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Benjamin Michael Smith

NATURAL RADIOACTIVITY IN MAINE AND
NEW HAMPSHIRE GROUND WATER SUPPLIES

A THESIS

Presented to

the Faculty of the Graduate Division

by

Benjamin Michael Smith

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NATURAL RADIOACTIVITY IN MAINE AND

NEW HAMPSHIRE GROUND WATER SUPPLIES

Approved:

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SUMMARY

As a part of recent scientific endeavors to evaluate increased human exposures to radiation, it has been found necessary to investigate naturally occurring radioactivity. This study concerns the occurrence and extent of natural radioactivity in ground water supplies. Locations chosen for the study included the Raymond, Yarmouth, Rumford, and Lewiston areas of Maine and the Nottingham, Dover, Deerfield, Grafton, and Franklin areas of New Hampshire, some of which were known to contain radioactive ground water supplies. Concentrations of Radium-226 and Radon-222 plus daughter products through Polonium-214 in water were determined.

A de-emanation method was chosen for the analysis of radon and radium in water. Use was made of existing geologic information to define insofar as possible any correlation between geologic formation and concentration of radioactivity in water. With the use of the data from approximately 350 sampling points, efforts were made to determine the variation of activity in ground waters with depth of wells, with geographic location, and with duration of pumping of water from wells. A limited study was conducted on radon removal by means of several water treatment methods.

It was clearly established that considerable quantities of Radon-222 were present in a majority of the ground waters of both states. Approximately 99.2 per cent of the water samples from drilled wells and 84 per cent of the water samples from dug wells in the State of Maine and all the water samples from New Hampshire contained concentrations of Radon-222

plus daughters exceeding 2,000 $\mu\mu c/\ell$, the maximum allowable concentration according to the National Committee on Radiation Protection. The average concentrations of Radon-222 plus daughters in well and spring waters were 53,700 $\mu\mu c/\ell$ in Maine and 101,000 $\mu\mu c/\ell$ in New Hampshire. Both in Maine and in New Hampshire, Radon-222 was found to be in excess of the equilibrium value with the Radium-226 present in the ground waters.

Over large areas, well depth was found not to significantly influence the radon activity of well waters. When the area was reduced in size to only a few square miles, radon activity was found to vary linearly with depth. Drilled wells were found to contain significantly greater concentrations of radon than dug wells. From tests for statistical significance, the average radon activities of both drilled and dug wells were found to vary significantly between several geographic and geologic areas and zones. There appears to be a more or less continuous band of high level radon activities associated with the drilled wells within a rather narrow geologic formation (or formations) following the general outline of the Fitchburg Pluton formation in New Hampshire and the Waterville formation in Maine.

Radon removal efficiencies obtained with several water treatment methods were as follows:

Faucet aerator	48 to 56 per cent
Faucet spray	17 to 18 per cent
Boiling	95 to 100 per cent
Treatment plant aerators	68 to 77 per cent .

CHAPTER I

INTRODUCTION

Available Information

An ever increasing interest in radioactivity and its applications has brought about the need for an assessment of human exposure to radiation. As a part of this program, it has been found necessary to examine naturally occurring radioactivity.

Although first observed in connection with certain minerals only, radioactivity has since been found to be associated with practically all minerals, rocks, and natural waters to some extent (1). Of special interest to the Sanitary Engineer is the occurrence of natural radioactivity in water. Most techniques for the disposal of radioactive wastes present the hazard of contamination of water supplies, either ground or surface. Surface supplies may also be contaminated with fall-out from nuclear explosions. The concentrations of naturally occurring radioactivity in water must be determined in order to more accurately evaluate artificial contamination. In nature, three extended series of radioactive elements exist: the actinium, the thorium, and the uranium series. Each of these has in common a gaseous member, a member with a very long half-life, and terminates in a stable isotope of lead.

Love (1) states that the actinium series has not been reported as occurring in natural waters in measurable quantities. Very little data are available on the concentrations of the thorium series in water. Skimokata (2), however, analyzed 53 Japanese waters and found three which contained concentrations of Thorium-232 of from 23 to 50 µg/ℓ, while the other fifty waters were found to contain none. Foyn, et al. (4), after examining a large number of samples, set an upper limit for the thorium content of sea water of 0.5 µg/ℓ. Kuroda, et al. (3), reports Thoron concentrations in spring waters at Hot Springs, Arkansas, of from 300 to 900 µµc/ℓ *. The half-lives of the members of the thorium series, other than thorium-232, are too short to permit their accumulation either in rocks or in water (1). Radium-224 and Radium-228, if present in water, is usually included in values reported for the more common Radium-226.

The uranium series has been encountered nore frequently in natural waters than the actinium and thorium series. Love (1), Lowder, and Solon (5) state that essentially all of the natural radioactivity of water may be attributed directly or indirectly to radium. Usually, Uranium-238 and Radium-226 are the only members of the uranium series found in water in detectable quantities (1). However, radon, which is a gas and the immediate daughter product of radium, may also be present in water in detectable amounts. Further, the immediate daughter products of radon with short half-lives may also be found in water in equilibrium with their common parent, radon.

Because of the balneological usage of natural mineral waters, the radioactivity content of many spring waters throughout the world has been determined. Values for many such springs are reported in Table 1.

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*One micro-microcurie (µµc) equals 2.22 disintegrations per minute of any radioactive substance. This disintegration rate is also defined as that of one micro-microgram (µµg) of Radium-226.

Table 1. Natural Radioactivity of Natural Waters

Source	Location	Uranium µg/ℓ	Radium µµg/ℓ	Radon µµc/ℓ	References
Mineral Springs	Japan	0.002 to 0.95			(6)
Spring Water	Vienna, Austria	0.36			(7)
Curie Spring	Boulder, Colorado		267,800	260,000	(8) (9)
Hot Spring	Masutomi, Japan		703,000		(10)
Spring Water	Shimane, Japan		709,800		(10)
Mangnesium Spring	Hot Springs, Virginia			93,000	(9)
Nauheim	Glen Springs, New York			26,000	(9)
Tiega Mineral Wells	Fitch Texas			2,000	(9)
White Sulphur Spgs.	West Virginia			860	(9)
Pluto Spring	French Lick, Indiana			490	(9)
Old Orchard Mineral Spg.	Missouri			430	(9)
Ten Springs	Syria and Leabanon		7 to 6,150		(11)
Hot Springs	Hot Springs, Arkansas			100 to 30,000	(3)
Cold Springs	Hot Springs, Arkansas			100 to 7,300	(3)
Spring Water	Potash Sulphur Springs, Ark.			6000 to 40,000	(3)
Clinch River	Tennessee				(10)
Susquehanna River	Pennsylvania		0.5 to 1.3		(12)
River Thames	Near Sutton Courtnay England		0.01		(13)
Public Water Supply	Barcelona, Spain		190 to 480		(14)
Public Water Supply	Frankfurt, Germany		3000 to 5000		(15)
Public Water Supply	41 U.S. Cities		0 to 6.5		(15)
Drinking Water	Prague, Czechoslovakia	18.9			(7)
Ground Water	(Non-Sandstone) Illinois		1		(16)
Ground Water	(Deep-Sandstone) Illinois		1 to 25		(16)
Well & Spring Waters	Illinois			50 to 2,900	(17)
Deep Wells	Near Chicago, Illinois		5		(5)
Normal Ground Water	U.S. Near A.E.C. Sites (25 samples)		0.58 to 3.90		(1)
Normal Surface Water	U.S. Near A.E.C. Sites (15 samples)		0.36 to 3.41		(1)
River Waters	North America	0.016 to 0.040	0.03		(6)
River Waters	(Average)	1.0	0.07		(18)
Great Salt Lake	Utah		5		(6)
Sea Water	(Range)	1.1 to 1.7			(19)
Sea Water	(Average)		0.08		(20)

Kohman and Saito (6) and Hoffman (7) report concentrations of uranium in spring waters ranging from 0.002 to 0.95 μg/ℓ. The maximum published value for the radium content of spring waters in the United States is for the Curie Spring at Boulder, Colorado, with 267,800 μμc/ℓ (8). Kuroda (10) reports maximum values for radium of 703,000 μμc/ℓ for a hot spring at Masutomi and 709,800 for a spring at Shimane, Japan. Concentrations of radioactivity in hot springs are usually much higher than would be expected for normal lakes and rivers (5).

The radium content of normal ground waters in the United States is reported as ranging from 0.58 to 3.90 μμg/ℓ (1). Lucas and Ilcewicz (16) have reported Radium-226 concentrations of less than one μμg/ℓ in ground waters of non-sandstone origin and from one to 25 μμg/ℓ in waters from three water-bearing, sandstone formations within the State of Illinois.

The radon activity of hot spring waters from Hot Springs, Arkansas, was found to be extremely variable from 100 to 30,000 μμc/ℓ as reported by Kuroda, _et al_.(3). The radon content of cold spring waters from the same area were found to vary between 100 and 7,300 μμc/ℓ. Spring waters collected from a uranium-vanadium-niobium prospect at Potash Sulphur Springs, Arkansas, contained less variable radon concentrations of from 6,000 to 40,000 μμc/ℓ (3). Radon concentrations in various other spring waters in the United States and other countries have been reported by Placak and Morton (9) and are presented in Table 1.

The radon content of deep wells at Hope and Prescott, Arkansas, are reported by Kuroda, _et al_.(3), and range between 50 and 1,880 μμc/ℓ as is shown in Table 2. As may be observed from the table, wells with depths less than 1000 feet contain much more radon than those with depths greater than this amount.

Table 2. Radon Content of Deep Wells at Hope and Prescott, Arkansas (3)

Well Designation	Depth (ft)	Radon Activity ($\mu\mu c/\ell$)
Hope		
Airfield	207	1,370
D W-2	620	1,760
D W-3	620	1,880
W W-11	1050	80
D W-1	1480	90
D W-5	1500	60
Prescott		
4	1070	50
2	325	1,650
3	325	1,660

Surface waters are known to contain much less radioactivity than ground waters, specifically, river waters in North America have been found to contain uranium concentrations of from 0.016 to 0.040 $\mu g/\ell$ by Kohman and Saito (6). Koczy (18) found a higher average uranium content in river waters of 1.0 $\mu g/\ell$ and an average radium content of 0.07 $\mu\mu c/\ell$.

In most natural waters, radium and radon are not in equilibrium (15) (21) (22). Radon is generally found to be in excess of its equilibrium value with radium; however, in surface waters, radium may be found in excess of equilibrium due to the removal of radon from water by aeration. A similar deviation from the theoretical equilibrium between uranium and radium in different parts of the sea has been previously reported by Evans (20), Petterson and Rona (23), and Piggot (24). A typical relationship between radium and radon in water is presented by Hursh (15) and shown in Table 3.

Table 3. Comparison of the Activities of Radon-222 and Radium-226 as Measured for Springs in the Vicinity of Rochester, New York (15)

Spring No.	Radon-222 (μμc/ℓ)	Radium-226 (μμc/ℓ)	Radon to Radium ratio
1	362	2.6	139
2	2970	1.3	2280
3	6200	1.4	4429
4	2695	1.3	2073

Variation in the radon content of a single spring water source has been observed and partially explained by Kikkawa (25). He shows that the radon activity of a spring water varies with rainfall, temperature, and discharge velocity. Love (1) states that mine waters in Czechoslovakia displayed an increase in radioactivity with increased depth. Radium concentrations of 13,500 and 163,800 μμg/ℓ were found at depths of 60 to 500 meters respectively. These mine waters are known to have been in contact with uranium deposits.

Most of the naturally occurring radioactivity found in water is probably derived from rocks and minerals with which the water has been in contact. Radioactive gases from molten magma within the earth may also be dissolved in ground waters in some areas.

The average radium content of igneous rocks in eastern North America has been determined by Piggot (26) (27) (28) (29) as being 0.9 μμg/g of rock. Evans (20) places the average concentrations of radium in igneous rocks at one μμg/g of rock. Piggot also reports that the radium concentrations of granites obtained at North Jay, Maine, and Stone Mountain, Georgia, are 3.39 and 3.81 μμg/g of rock respectively. Normally, sedimentary rocks contain much less radium than igneous rocks. Values ranging from less than 0.04 to 2 μμg/g of rock have been reported (1).

Delineation of the Problem

The opportunity to study at first hand natural waters known to contain detectable amounts of natural radioactivity was presented in the fall of 1958 after radioactivity had been accidently discovered in a deep well water supply at Raymond, Maine. A thirteen year old boy was checking a water pressure tank with a portable beta-gamma survey meter and observed a high count rate.

In April, 1959, both the New York and the New Hampshire State Health Departments reported similar discoveries of natural radioactivity in ground water supplies. In the state of New Hampshire, "three of five domestic wells near Nottingham (about halfway between Concord and Portsmouth, N.H.) had a gross beta activity up to 10^5 μμc/ℓ with appreciable quantities of alpha activity (up to 10^4 μμc/ℓ)" (30).

The results of analyses of well waters obtained from the Raymond, Maine, area (See Table 4) seemed to establish that uranium, radium, and radon and its daughter products are present. The reported radon activity for samples obtained from the Dielectric Company exceeded the maximum allowable concentration almost 300 times, while the same sample showed a maximum value of 1.6 times the maximum allowable concentration for radium *. Although the comparison in Table 4 refers to one well only, additional analyses on other well water supplies performed by the State Health Department of Maine confirmed a similar high radon activity. Results from the eight radium and uranium analyses reported by the U.S. Geological Survey demonstrate further that the radium concentrations are in general less than the maximum allowable concentration for drinking water.

Beginning in April, 1958, water samples from more than 45 wells in the Raymond and Windham areas of Maine were analyzed for radioactivity by the U.S. Public Health Service and the State Health Department of Maine. The activity of radon plus daughters was found to vary from 2,500 to 588,000 $\mu\mu c/\ell$. The long-live alpha activity, primarily uranium, thorium, and radium, was found to vary from zero to 666 $\mu\mu c/\ell$. It may also be noted that the geological survey of this area indicates a rather high background radiation (34). It has been reported by van der Smissen and Weiss (35) that there exists an outcrop of Samarskite ** approximately 12 miles east of Raymond.

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*The maximum allowable concentration of Radon-222 plus daughters is 2,000 $\mu\mu c/\ell$ and of Radium-226 is 40 $\mu\mu c/\ell$ according to Handbook 61 (33).

** The nominal composition of Samarskite is: (Y, Ce, U, Ca, Fe, Th) $(Nb, Ta, Ti, Sn)_2 O_6$ with an average range of 8.4 to 16.1 per cent uranium content and less than 3.7 per cent thorium content (36).

Table 4. Radioassays of Well Waters in Maine (prior to 1959)

Source	Radon-222 + daughters ($\mu\mu c/\ell$)	Radium-226 ($\mu\mu c/\ell$)	Uranium ($\mu g/\ell$)	Long-lived Alpha Activity ($\mu\mu c/\ell$)
SAMPLES FROM DIELECTRIC PRODUCTS ENGINEERING CO., INC., RAYMOND, MAINE (30)				
R. A. Taft Sanitary Engineering Center	583,000			520
Occupational Health Field Station	228,000	64	860	666
State Health Dept. of Maine	563,410	45		420
OTHER SAMPLING POINTS BY U.S. GEOLOGICAL SURVEY (32)				
(Agusta Water Dept., Augusta)		0.1	0.8	
(T.G. Weigand, Vassalboro)		0.1	0.1	
(Sheldon S. Grant Windham)		3.3	11	
(Raymond Water Co., Raymond)		0.1	0.2 $\pm$ 0.1	
(Portland Water Supply, N. Windham)		0.1	1 $\pm$ 0.1	
(Charles Harmon, Raymond)		0.5 $\pm$ 0.1	34 $\pm$ 3	
(Dielectric Prod. Eng. Co., Inc., Raymond)		57 $\pm$ 2	960 $\pm$ 96	
(Portland Pipeline Co., Raymond)		0.1	110 $\pm$ 11	

Consequently, a study to define the occurrence and extent of natural radioactivity in ground water supplies in the areas of Maine and New Hampshire where activity had been reported was initiated in December, 1958, by the author and Mr. F. B. Higgins, both graduate students in Sanitary Engineering at the Georgia Institute of Technology. A detailed sampling program was pursued for approximately seven weeks during the summer of 1959. Six of the seven weeks were devoted to sampling in Maine and one week to selected areas in New Hampshire. The program in Maine included radioassay of ground water supplies in the Raymond, Yarmouth, Rumford, and Lewiston areas. In New Hampshire samples were collected from areas in and around the towns of Nottingham, Northwood, Deerfield, Grafton, and Franklin. In addition, the water supply sources and system for the City of Dover, New Hampshire, a city of about 20,000 persons, were studied in some detail.

CHAPTER II

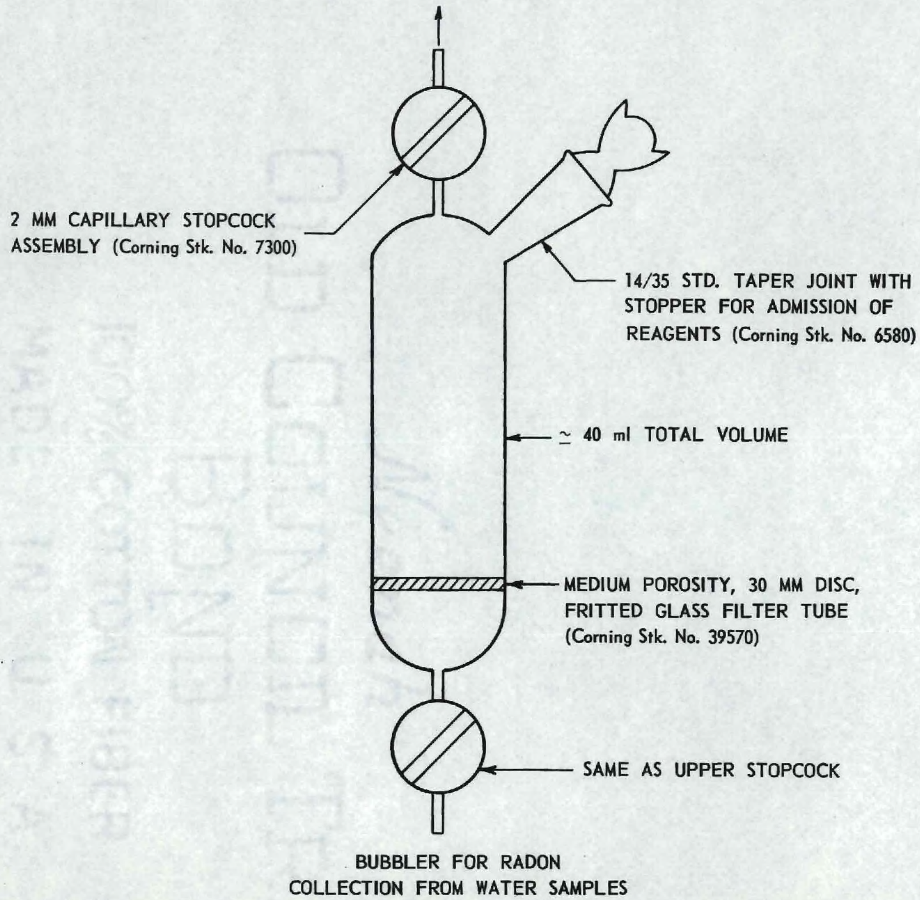
EXPERIMENTAL APPARATUS

After considerable experimental work, it was decided to adopt the de-emanation method for the analysis of radon and radium for the sampling program. The method is similar to that used by Holaday, et al. (37), for the detection of radon in air within uranium mines. A more comprehensive discussion of the method and techniques used in this study has been presented by Higgins (38).

Most of the major items of equipment required for this study were not readily available. These items included glass sampling devices or bubblers, scintillation flasks, and a scintillation detection unit. They were specially designed and constructed at the Georgia Institute of Technology.

The special type of glass bubbler, designed for the purpose of separating radon from water, is shown in Figure 1. Of the 40-ml bubbler capacity, 25 ml were used for the liquid sample, while the remaining space provided for the expansion of the liquid upon aeration. The required air-water interface and agitation for the de-emanation of radon were supplied by fritted glass filters which functioned as diffuser plates. The stopcock assemblies provided a control for the flow of air through the bubblers, and glass stoppers permitted the admission of water samples and reagents to the bubblers.

SKETCH OF BUBBLER AND SCINTILLATION FLASK



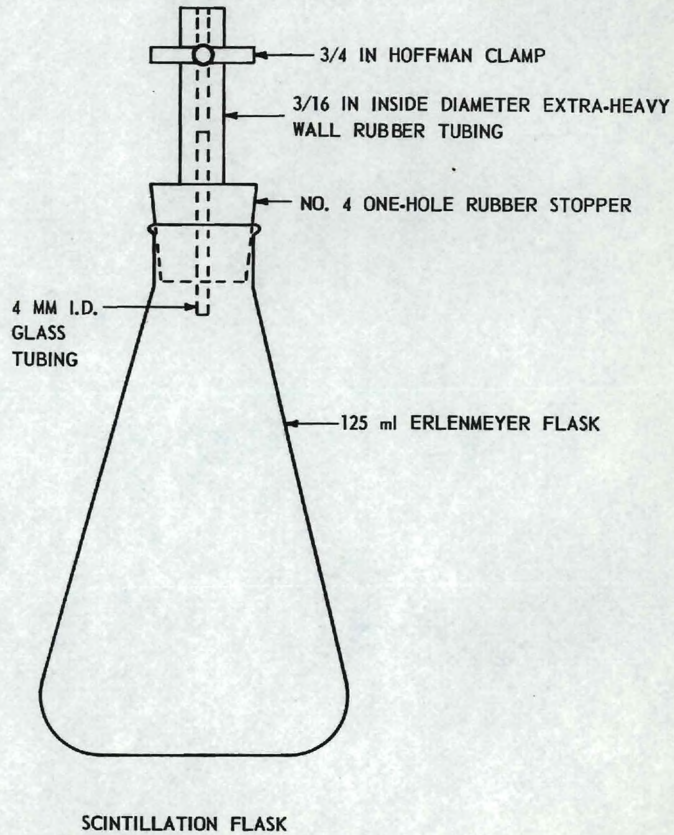


Fig. 1. Sketch of Bubbler and Scintillation Flask

Air, which was used as the de-emanation gas, was allowed to enter a bubbler through its lower capillary tube and stopcock. The gas then flowed through the fritted glass filter where it was diffused and broken up into tiny bubbles. Agitation caused by this diffused air facilitated the scrubbing of radon and other entrained gases. Upon evolution from the bubbler, the gases then flowed through the upper capillary tube and stopcock assembly and into a scintillation flask.

Erlenmeyer flasks of 125-ml capacity provided suitable scintillation flasks. Each flask was equipped with a one-hole rubber stopper fitted with a short piece of glass tube, a short section of rubber pressure tubing, and a screw clamp. The stopper assemblies were made sufficiently tight so that the flasks could be evacuated and hold a vacuum for several hours. A Cenco vacuum pump * was used to evacuate the flasks. To provide a scintillation screen, for the detection of alpha particles, the interior surfaces of the flasks were coated with a thin layer of zinc sulfide **. The coating procedure employed was similar to that proposed by Harris, LeVine, and Watnick (39). The bottom ends of the one hole stoppers were coated also, but the inside bottoms of the flasks were carefully left clear. The transparent bottoms provided windows for an efficient light path to the photomultiplier tube of the detection unit.

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*Cenco-Hyvac vacuum pump produced by the Central Scientific Company, Chicago, Illinois (0.0003 mm Hg vacuum)

** The density of the zinc sulfide coating was 5.71 ± 0.85 gm per sq cm as based on 19 determinations.

Three types of silver-activated, zinc sulfide phosphor were used during the sampling program *. The duPont Company's phosphor was used for most of the sampling. However, the U.S. Radium Corporation's phosphor and the General Electric phosphor were used toward the end of the sampling program for the analysis of samples from New Hampshire. The U.S. Radium phosphor had a greater light-holding capacity and was therefore inefficient for mass analysis. A time interval of at least five minutes was required for the light retained to die out, whereas the other phosphors required only about fifteen seconds.

Figures 2 and 3 show the water pressure tank and wash basin at the Dielectric Products Engineering Company, Inc., where the initial discovery of radioactivity in a ground water supply in Maine was made. A bubbler and a scintillation flask being used at this sampling point by the author may be seen in Figure 3.

The special scintillation detector used in the study is presented diagrammatically in Figure 4. The detection unit consisted of a photomultiplier tube, a preamplifier, a pulse amplitude discriminator, and a low voltage power supply. The high voltage required for operation of the detector and a device for registering the amplified pulses from the photomultiplier tube were supplied by a nuclear scaler * *.

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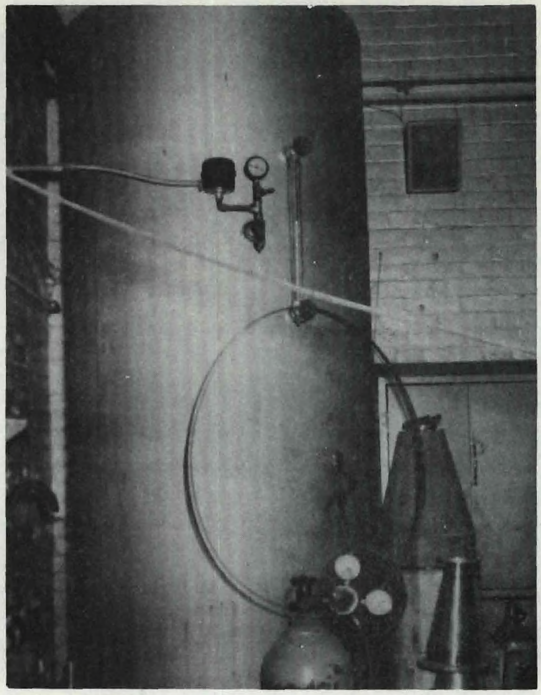
*1. E.I. duPont de Nemours and Company's Luminescent Chemical, Type D, Lot 68.
2. U.S. Radium Corporation's Radelin Phosphor, Color Number 920 B.
3. General Electric TV phosphor.

**Nuclear Chicago, Model 186 "Imperial" Scaler, Nuclear Chicago Corporation, Chicago, Illinois.



WATER PRESSURE TANK AT DIELECTRIC PRODUCTS ENGINEERING CO., INC., RAYMOND, MAINE
Fig. 2.

SAMPLE COLLECTION FROM A WASH BASIN
(Dielectric Products Engineering Co., Inc., Raymond, Maine)
Fig. 3.

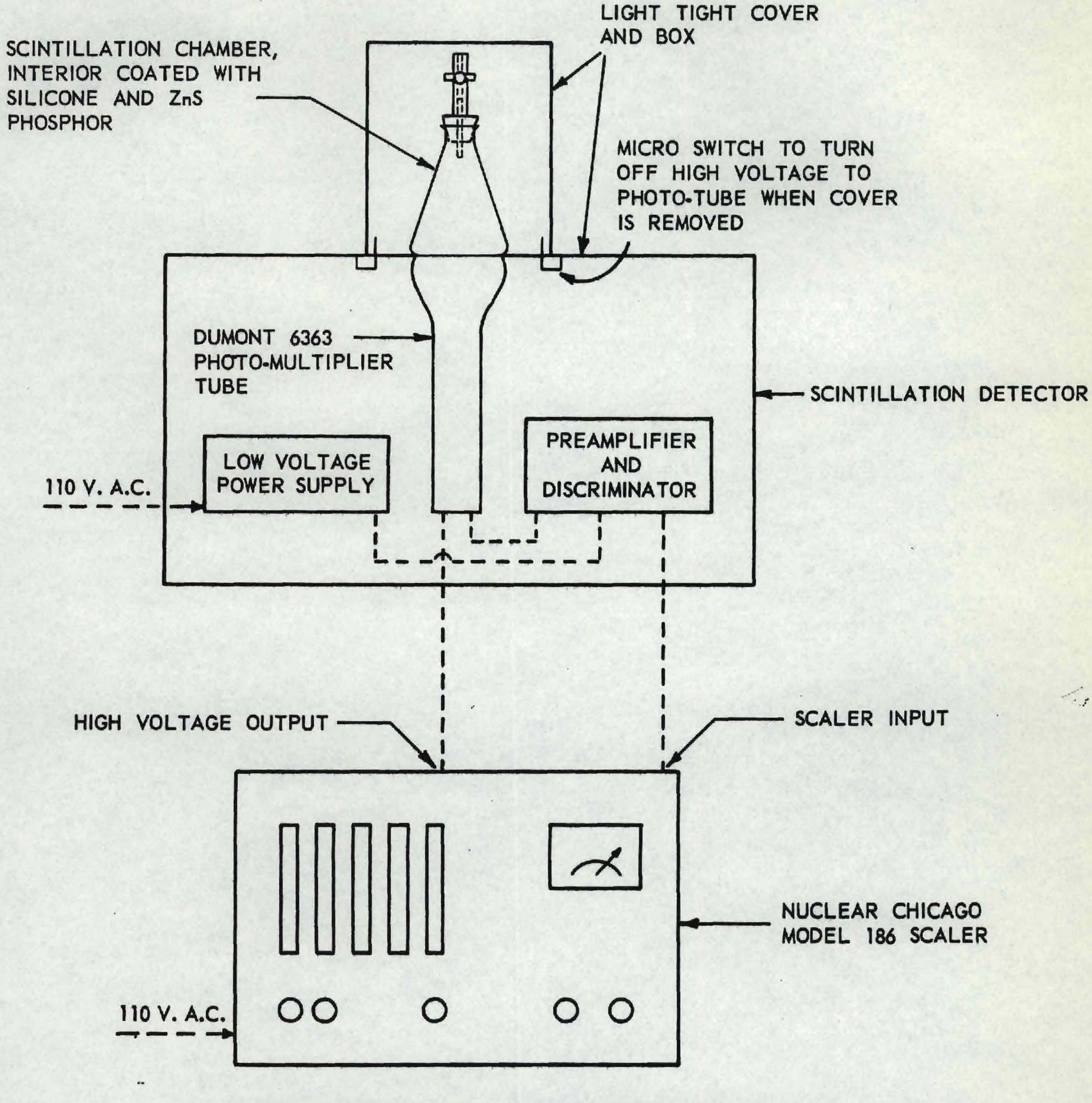
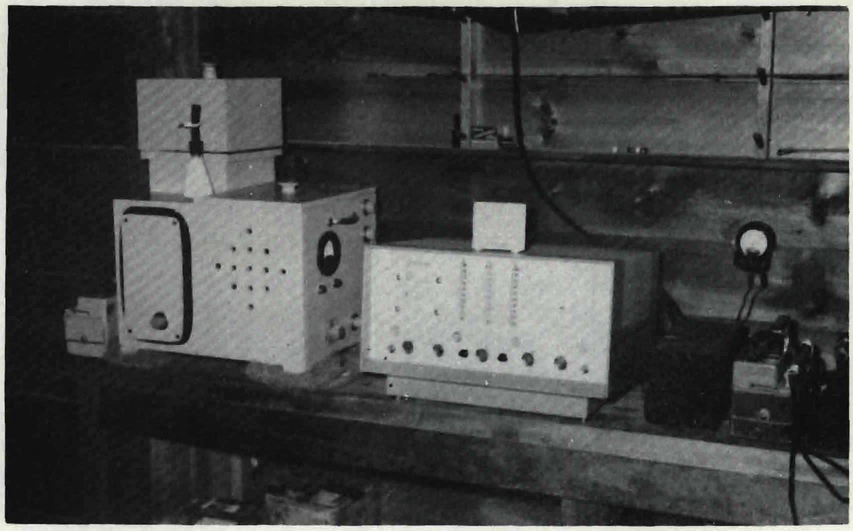


Fig. 4. Sketch of Scintillation Detector and Scaler

Figure 5 shows a part of the field laboratory as set up at Raymond, Maine, where most of the water sample analyses for Maine were performed. Most of the bench space is taken up by the scintillation detector on the left and the nuclear scaler in the center.

To maintain a constant line voltage for the scaler and the detector, a 250-watt Sola voltage regulator transformer was employed and is shown to the right of the scaler. Line voltage was checked continuously with the voltmeter shown mounted on the wall above the Sola transformer. On both the right and the left ends of the bench may be seen the beta-gamma survey meters which were used in conjunction with the field study.

A section of the field laboratory at Nottingham, New Hampshire, is shown in Figure 6. Several zinc sulfide coated scintillation flasks and bubblers are shown on the table on the left. Shown also in the figure are the author and Mr. Higgins, the survey team.



FIELD LABORATORY SET-UP AT RAYMOND, MAINE
(Scintillation Detector and Scaler on Bench)
Fig. 5.

FIELD TEAM IN THE NOTTINGHAM, NEW HAMPSHIRE, LABORATORY
Fig. 6.

CHAPTER III

EXPERIMENTAL PROCEDURE

Procedure for Performing the Radon Analyses

The sampling and analytical procedures described below, those which were employed in this study, are presented in more detail by Higgins (38). The technique involved the collection of a water sample with minimum aeration, removal and collection of radon from the water, and analysis of the water for alpha activity by scintillation counting.

After a thorough cleaning, each of the bubblers was prepared for sampling by inserting one ml of concentrated nitric acid through the tapered joint. This produced a solution of approximately 0.5 N acid concentration with the sample. The reason for the addition of acid was to reduce contamination of the bubblers by keeping dissolved materials in solution. The final preparatory step before sample collection was the weighing of each bubbler for a subsequent determination of sample volume.

After a water sample had been collected, radon was removed from the bubbler to a scintillation flask. This was accomplished by connecting the upper capillary tube of the bubbler to an evacuated scintillation flask and allowing air to flow through the sample.

The vacuum-induced flow of air through the bubbler was broken up by the glass, diffuser plate into fine bubbles which scrubbed the radon from the sample. When the flow of air was started, care was taken that none of the water was drawn into the scintillation flask thereby damaging the zinc sulfide coating and introducing other radioactive materials into the subsequent radioassay. After bubbling ceased, the rubber tubing clamp was tightened to seal off the radon in the flask, and the bubbler was stored for transportation to the laboratory.

A partial vacuum remained in the flasks at the termination of bubbling due to head losses induced by the fritted glass filters. To remedy this situation and to standardize the pressure within the flasks, the clamps were always opened slightly to bring the pressure inside the flasks to atmospheric. Then the clamps were immediately retightened to prevent the escape of any radon to the atmosphere.

Since air was used to remove radon from the water, special measures were necessary to account for the radon concentrations of air used for bubbling. The problem was solved by collecting an air sample in a scintillation flask each time radon de-emanation was conducted. These background flasks were counted in the laboratory and the results used as a background count for absolute calculations.

Sample analysis in the laboratory was a rapid and simple procedure. First, each bubbler was weighed again to determine the precise sample volume. The sample and the background flasks were then counted to complete the analysis. A preset counting time of 20 minutes was used for all radon analyses. Five minute background counts were considered adaquate (38).

Special attention was given to two steps of the laboratory analysis: (1) The flasks were always centered on the phototube to insure the same geometry, and (2) at least four hours were allowed to elapse from the time of de-emmanation to the start of the counting period. This period of time insured an equilibrium between radon and its daughter products and decay of the total alpha activity with the radon half-life as may be seen from Equation (1).

$$\frac{A_t}{A_o} = 3.009e^{-0.0001258t} - 1.024e^{-0.2273t} - 4.280e^{-0.02586t} + 3.295e^{-0.03519t} \quad (1)$$

where:

t = time in minutes

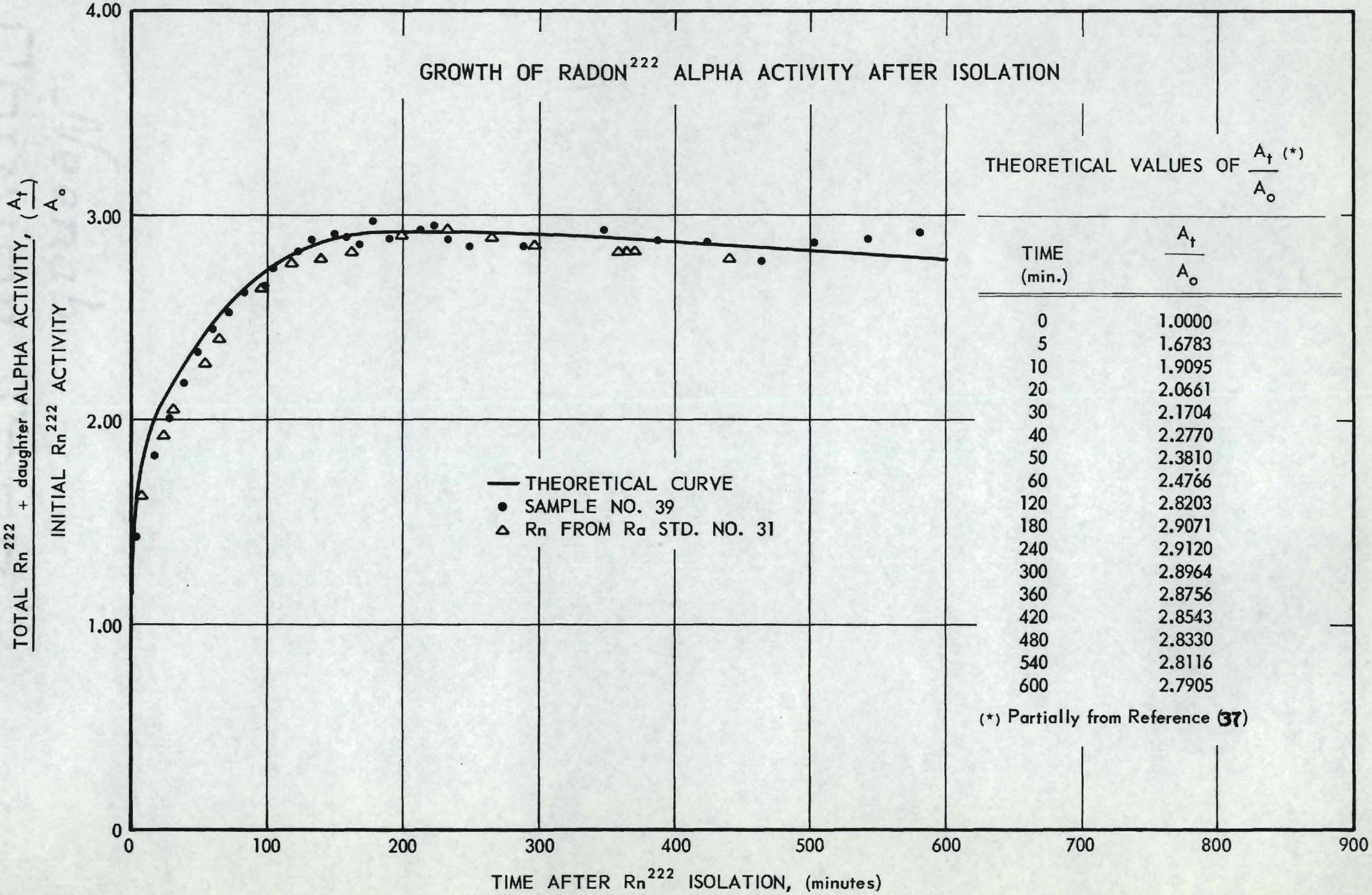
A_o = initial activity

A_t = activity at time t.

This condition obviated any correction for decay during counting over normal counting intervals because of the slow rate of change of the total activity.

A plot of the theoretical growth equation (Equation 1) is shown in Figure 7. The curve represents the growth and decay of alpha activity for Radon-222 plus daughters. Superimposed on this curve are experimental points obtained for radon both from a standard solution of Radium-226 and from an analysis of water obtained from sampling point No. 39.

A sample calculation of the actual radon activity from data derived in the laboratory is presented in Appendix A.



THEORETICAL VALUES OF $\frac{A_t}{A_o}$ (*)

TIME (min.)	$\frac{A_t}{A_o}$
0	1.0000
5	1.6783
10	1.9095
20	2.0661
30	2.1704
40	2.2770
50	2.3810
60	2.4766
120	2.8203
180	2.9071
240	2.9120
300	2.8964
360	2.8756
420	2.8543
480	2.8330
540	2.8116
600	2.7905

(*) Partially from Reference (37)

Fig. 7. Growth of Radon^{222} Alpha Activity After Isolation

Adaptation of the De-emanation Method to Radium Analysis

The method of analysis as described for radon was adapted for the analysis of radium by simple changes in procedure. However, because of the low concentrations of radium normally present in natural waters and the small sample capacity of the described bubblers, the accuracy of the determination was not as good as that for radon.

The procedure for radium analysis involved the storing of a sample of water for a known length of time to allow the buildup of radon from radium followed by a determination of the radon content. The same samples and bubblers used for the radon analyses were therefore used again later for the determination of radium.

After radon analysis, each sample to be analyzed for radium was thoroughly purged of any remaining radon. Purging was easily accomplished by bubbling the sample vigorously with air for two to three minutes. A partial vacuum was left in each bubbler after complete radon removal to insure that no radon leakage could occur during storage.

Each sample was then stored for a period of time to allow the radon to build up to a known percentage of its equilibrium value with radium. Radon buildup is a function of its half-life as shown by the following equation (40).

$$\frac{A_t}{A_o} = 1 - e^{-\lambda t} \qquad (2)$$

where: A_o = activity (constant) of radium

A_t = activity of radon at time, t

λ = decay constant of radon (0.693/ radon half-life)

t = time after isolation of radium.

Eight to ten days of storage was sufficient time to obtain an adequate radon concentration. For example, 8 and 10 days are required for A_t to equal 0.77 A_o and 0.84 A_o, respectively.

After storage, the analyses were performed as for radon except that thirty-minute counting periods were used for both sample and background and that an additional correction for the incomplete equilibrium between radon and radium was applied (38). Storage time was taken as the period between initial purging of radon and the time the sample was bubbled a second time with a scintillation flask for analysis. Sample calculations are shown in Appendix A.

Standardization of Method and Equipment

A primary radium standard was obtained from the National Bureau of Standards, Washington, D.C.. It contained 2 µc $\pm$ 0.7 per cent of Radium-226 in five ml of five per cent nitric acid by weight. The secondary standards for field use were prepared by successive dilutions from the primary standard to obtain concentrations of 2, 20, 200 and 2,000 µµc/ml. Portions of these secondary standards were sealed into five-ml, glass ampoules for later use. To insure a high degree of accuracy for these secondary standards, the ampoules were weighed before and after filling to accurately determine the volume of solution contained in each ampoule.

A determination of counting efficiency involved the transfer of a known volume of secondary standard to a bubbler, the addition of distilled water to bring the total volume to 20 to 30 ml, a period of ageing to allow radon buildup, radon removal from the bubbler, and a count of the scintillation flask.

Before storing the standard solution in the bubbler for radon buildup, all radon present in the standard was removed by bubbling so that a definite reference time could be established for radon buildup calculations. A partial vacuum was left in the bubbler to insure that any leakage during storage would be inward and not result in any loss of radon from the bubbler. The period of ageing was based on the degree of radon equilibrium desired and on available time. Eight days were selected as a minimum storage time to allow for a radon activity buildup of approximately 80 per cent of the radium activity as derived from an application of Equation (2).

An analysis for the efficiency of the method was performed by collecting the radon from a standard in a scintillation flask and counting it. A comparison of the theoretical activity with the observed activity yielded the overall efficiency of the analysis. After each bubbling of a standard, the standard was again purged and stored for a later analysis. Thus, a series of checks on efficiency was made over a period of time with the same standards. This procedure eliminated variations between the activities of standard solutions and allowed the detection of variations in the phototube.

The results of the analyses from a group of standards measured at five different times during the field sampling program are shown in Figure 8. The efficiency of scintillation detection varied from about 80 per cent to about 55 per cent during the period from July 16, 1959, to October 1, 1959. This variation may be explained in part by the fact that different zinc sulfide phosphors were used and that the sensitivity of the phototube decreased by normal decay.

On August 22, 1959, the field laboratory was moved to New Hampshire. There, the scaler sensitivity had to be readjusted after mechanical repairs had been performed. A recount of two flasks containing radon standards was performed to establish the new efficiency. This resulted in the portion of the efficiency curve (See Figure 8) between August 22 and August 27 and an increase in efficiency as shown in Figure 8. Some doubt still exists about the exact shape of the curve from August 27 to September 14 since a third brand of zinc sulfide had to be substituted before the fifth standardization series was run. Only one set of standards was run during this period with each brand of zinc sulfide phosphor. However, since the slope of the curve through the two points is compatible to the shape of the initial part of the curve, the same trend was continued. Errors in the results obtained during the latter period were minimized by the fact that counting was done only during periods slightly before and after each of the two efficiency determinations.

To properly evaluate data obtained from different bubblers, it was necessary to separate the radon removal efficiency from the overall efficiency of the analysis since differences between bubblers existed due to the use of diffuser plates from two manufacturers. Separate radon

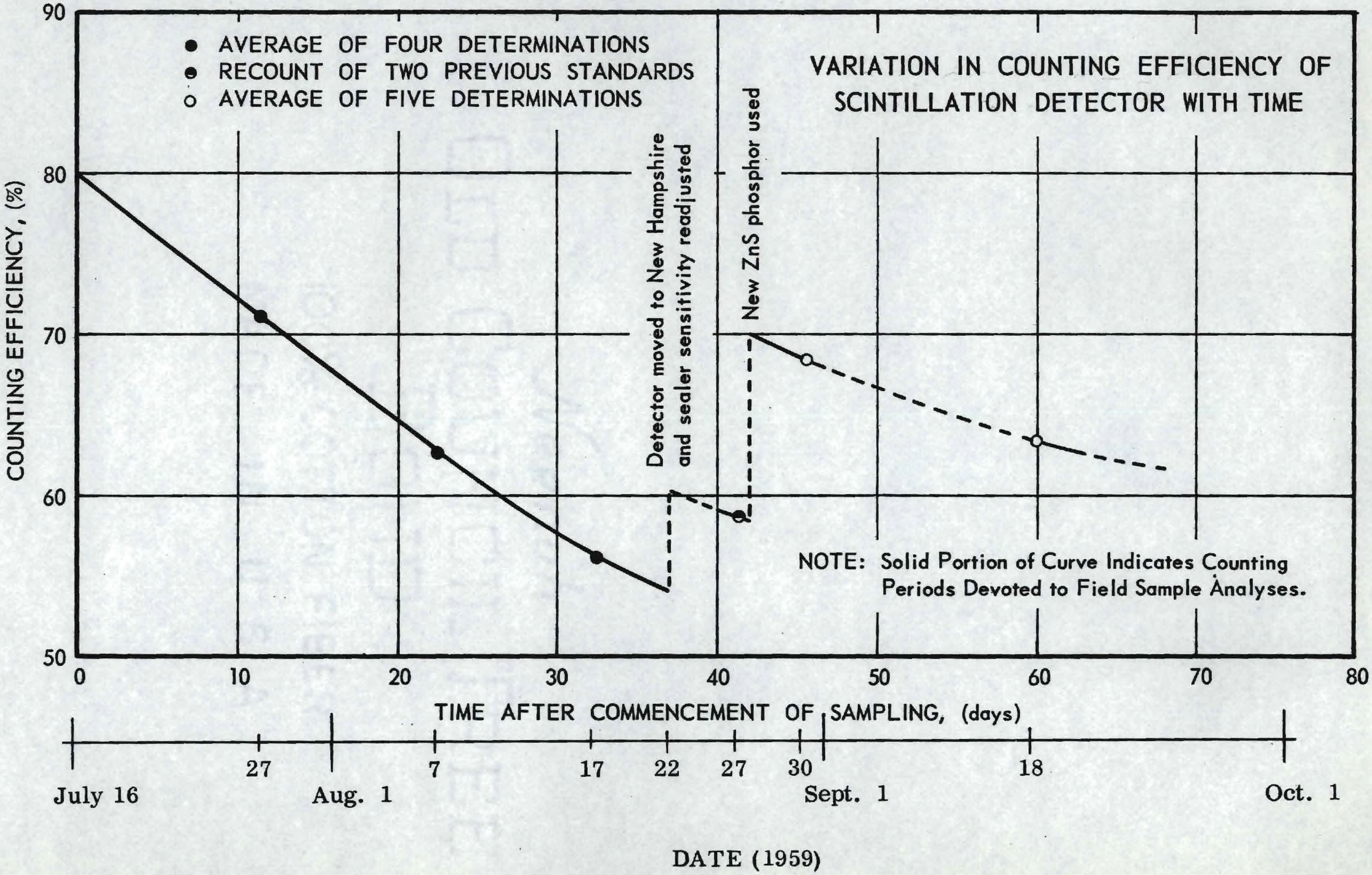


Fig. 8. Variation in Counting Efficiency of Scintillation Detector With Time

removal efficiencies were established for a representative group of both types of bubblers by successive de-emanation of samples until practically all radon was removed. The sum of the activities obtained from each experimental sample was taken as the total radon concentration of the sample. Radon removal efficiency of a bubbler was then determined by comparing the activity of the first de-emanation with the total activity measured. These values were applied to each sample calculation to compensate for any incomplete removal of radon from the water.

Reproducibility of the Method

The reproducibility of the method was determined from the statistical analyses of two different groups of data. The first group of data was composed of the counting efficiencies of several analyses each of five standard solutions. The second group of data consisted of nine triplicates of samples from two sampling points. The statistical test of results obtained from the standard solutions was based on data from 22 analyses. These results represented five analyses each from two radon standards of approximately 400 $\mu\mu c/\ell$, five analyses each from two radon standards of approximately 160,000 $\mu\mu c/\ell$, and two analyses from one standard of approximately 40,000 $\mu\mu c/\ell$. The distribution of data was tested for normality and the 95 per cent confidence limits established.

Since the arithmetic means of the standard analyses varied with time (See Figure 8), the standard deviation could only be expressed on a precentage basis. The standards were first analyzed as a group. The data proved to be fairly normally distributed. The standard deviation was found to be 5.18 per cent and 95 per cent of the time (1.96σ), the values fell within ± 10.2 per cent of the mean.

The high and the low activity standards were also analyzed separately to determine whether the counting error of the low activity standards caused an increase in the range at the 95 per cent level of significance. The results showed a standard deviation of 4.53 per cent and a range of ± 8.88 per cent (at the 95 per cent level) for the high standards. A standard deviation of 5.12 per cent with a range of ± 10.0 per cent (at the 95 per cent level) was found for the low standards. The high activity standards showed only a slightly better reproducibility than those with lower activities.

The same statistical methods were employed in analyzing the triplicate samples. The distribution found was quite normal as shown by the ratio $\sigma/A.D. = 1.24$. The standard deviation was 4.69 per cent, and the range was found to be ± 9.19 per cent (at the 95 per cent level).

From a comparison between the standard deviation of the results from the standard solutions and the triplicate samples, it was found that the method of sample collection exerted no real effect on the reproducibility. Since a certain percentage of radon may have been lost during sample collection, however, statistical analyses could not be based on absolute activities.

CHAPTER IV

DISCUSSION OF RESULTS

General Description of Field Data

During July and August of 1959, approximately 350 water samples were collected in Maine and New Hampshire. Of these, 304 samples were collected from Maine, but because of duplication at several points, this number was reduced to 234 samples for all types of water supplies including two surface supplies. Of all the samples, 204 were obtained from drilled and dug wells. A total of 128 drilled wells were examined in Maine.

A total of 46 samples for all types of supplies were collected in New Hampshire. Of these, 21 samples were collected from various points of the Dover, New Hampshire, Municipal Water Supply System. The results of this detailed study are described separately in a later section. Of the remaining 25 samples from New Hampshire, 17 came from drilled wells and the remainder from dug wells, a driven well, and a spring. In the presentations to follow, these classifications of samples were preserved insofar as possible. The samples enumerated above refer only to those analyzed for Radon-222. The samples which were also analyzed for Radium-226 number considerably less, approximately 85, due to the small number of bubblers (50 in all) available for the study.

A total of 150 samples from Maine and New Hampshire were also analyzed for Lead-210, a 0.023 mev beta emitter, but no significant concentrations were found (38). This may be attributed to the present state of development of the dithizone method as used in the analysis and/or the fact that lead compounds are relatively insoluble in water (38).

A complete tabulation of the field data is presented in Appendix B and includes, for each sample analysis reported, the following information:

1. Sample number
2. Name of household, industry, or other users
3. Location
4. Use of well, domestic, commercial or industrial
5. Number of persons using well
6. Ages of persons using water from the well
7. Date family began to use the water supply
8. Type of well, dug, drilled, driven, jetted or gravel packed, and springs
9. Depth of well in feet
10. Date of sample collection
11. Activity of Radon-222 ($\mu\mu c/\ell$)
12. $\alpha + \beta$ Activity of Radon-222 plus daughters through Polonium-214 ($\mu\mu c/\ell$)
13. Activity of Radium-226 ($\mu\mu c/\ell$)

The samples which were analyzed for Lead-210 are referenced with an asterisk.

The geographical location of all the sampling points is presented on the map which forms Appendix C and is entitled "Approximate Location and Activity of Sampling Points in Maine and New Hampshire."

Identification of the Radon Activity

Two representative sampling points, Nos. 22 and 39, were selected in the Raymond, Maine, area for a careful determination of the exact type of radioactivity present in the well water. Duplicates from each sampling point, or four samples, were counted at twenty-five different times for a precise determination of radioisotope decay.

The samples were counted for twenty minutes each. The net counting rate, corrected for background and counting efficiency based on a National Bureau of Standards Radium-226 standard, was plotted on semi-log paper. To trace the radon decay, beginning from the time of de-emanation from one of these samples, the scintillation flask was counted for five-minute intervals over the first seven hours. With decreasing frequency, counting continued for eight additional days. A plot of the observed decay for sample No. 39 was presented along with the theoretical and radium-radon standard curves in Figure 7.

From a least squares treatment of the data as collected after an initial five-hour decay time, a decay curve of best fit was established. This curve is reproduced as Figure 9. The data exhibited a high degree of reproducibility as shown by a value of 0.995 for the coefficient of correlation. The equation fitted by the method of least squares is:

$$A_T = A_0 e^{-0.1796T - 0.010} \tag{3}$$

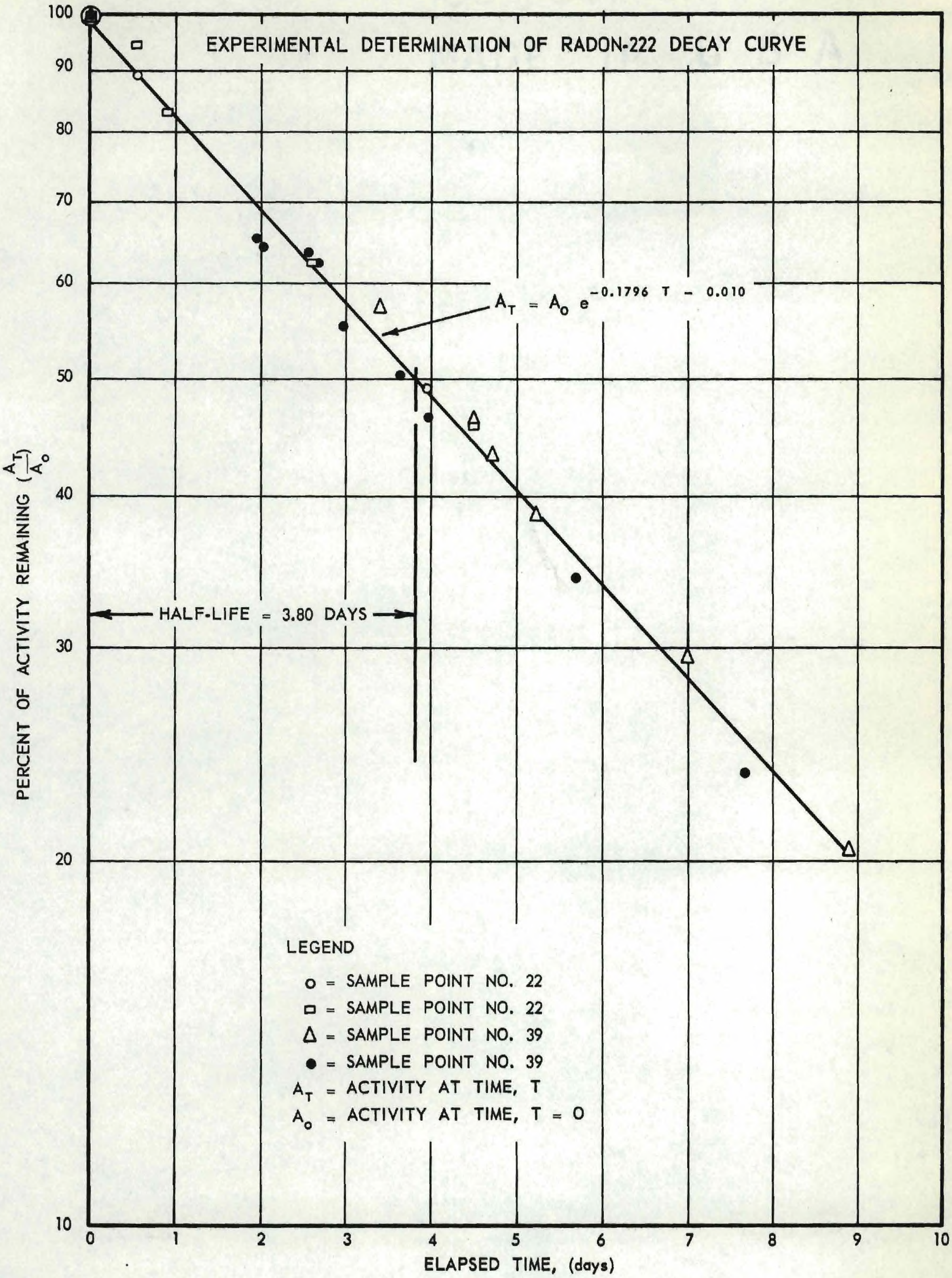


Fig. 9. Experimental Determination of Radon-222 Decay Curve

where: A_T = activity of Radon-222 at time, T

A_0 = initial activity of Radon-222

T = elapsed time, days.

From this expression, the time required for 50 per cent of the initial activity to decay (the half-life) was calculated to be 3.798 days. This experimental value compares quite favorably with the established 3.825 days half-life for Radon-222 (40). The very close agreement between the above values demonstrates conclusively that the gaseous radioelement determined was derived from the natural uranium series, Radon-222.

Distribution of Activity Encountered

A histogram of the radon* activities from all 128 drilled wells sampled in Maine shows that 27.3 per cent of the samples were between zero and 12,500 μμc/ℓ, as shown in Figure 10. Only samples with activities up to 300,000 μμc/ℓ are plotted, but the five additional samples with greater activities are listed. Both the histogram and the per cent frequency curves, however, are based on all 128 samples. The equation for the frequency curve of best fit from curvilinear correlation was found to be:

$$F = e^{10.5} A^{-0.822} \tag{4}$$

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*Radon as used in this chapter refers to Radon-222 plus daughter products through Polonium-214.

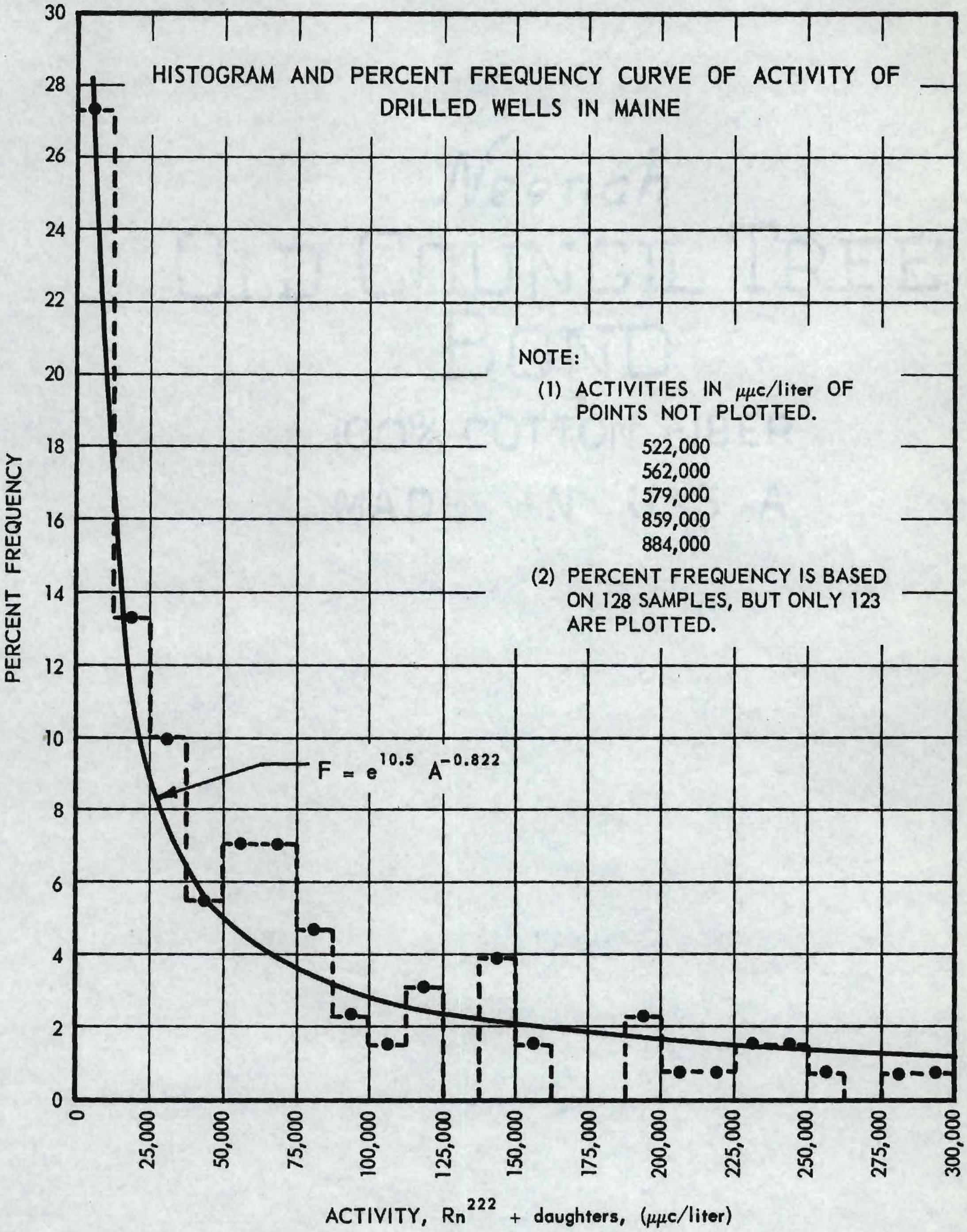

Fig. 10. Histogram and Percent Frequency Curve of Activity of Drilled Wells in Maine

where: F = per cent frequency

A = Radon-222 + daughters activity, $\mu\mu c/\ell$.

The cumulative frequency curve for activities of radon from drilled wells in Maine is shown in Figure 11. From calculations, 99.2 per cent of the samples showed activities equal to or greater than the maximum allowable concentration of 2,000 $\mu\mu c/\ell$. Actually, only one sample from a drilled well was found to have an activity below 2,000 $\mu\mu c/\ell$. The generalized curve further shows that:

90 per cent of all samples exceeded	4,000 $\mu\mu c/\ell$
50 per cent of all samples exceeded	37,000 $\mu\mu c/\ell$
10 per cent of all samples exceeded	220,000 $\mu\mu c/\ell$.

Similarly, Figure 10 shows that 11.5 per cent of the data exhibited an activity of 100 times the maximum allowable concentration (33).

The activities from 76 dug wells in Maine are presented in Figure 12. It shows that approximately 20 per cent of the dug wells had a radon activity of 2,500 $\mu\mu c/\ell$ or less. The maximum activity found for the dug wells was 31,700 $\mu\mu c/\ell$. From a curvilinear correlation, the equation for the frequency curve of best fit for dug wells was found to be:

$$F = e^{11.3} A^{-1.035} \tag{5}$$

with the units of F and A as defined above.

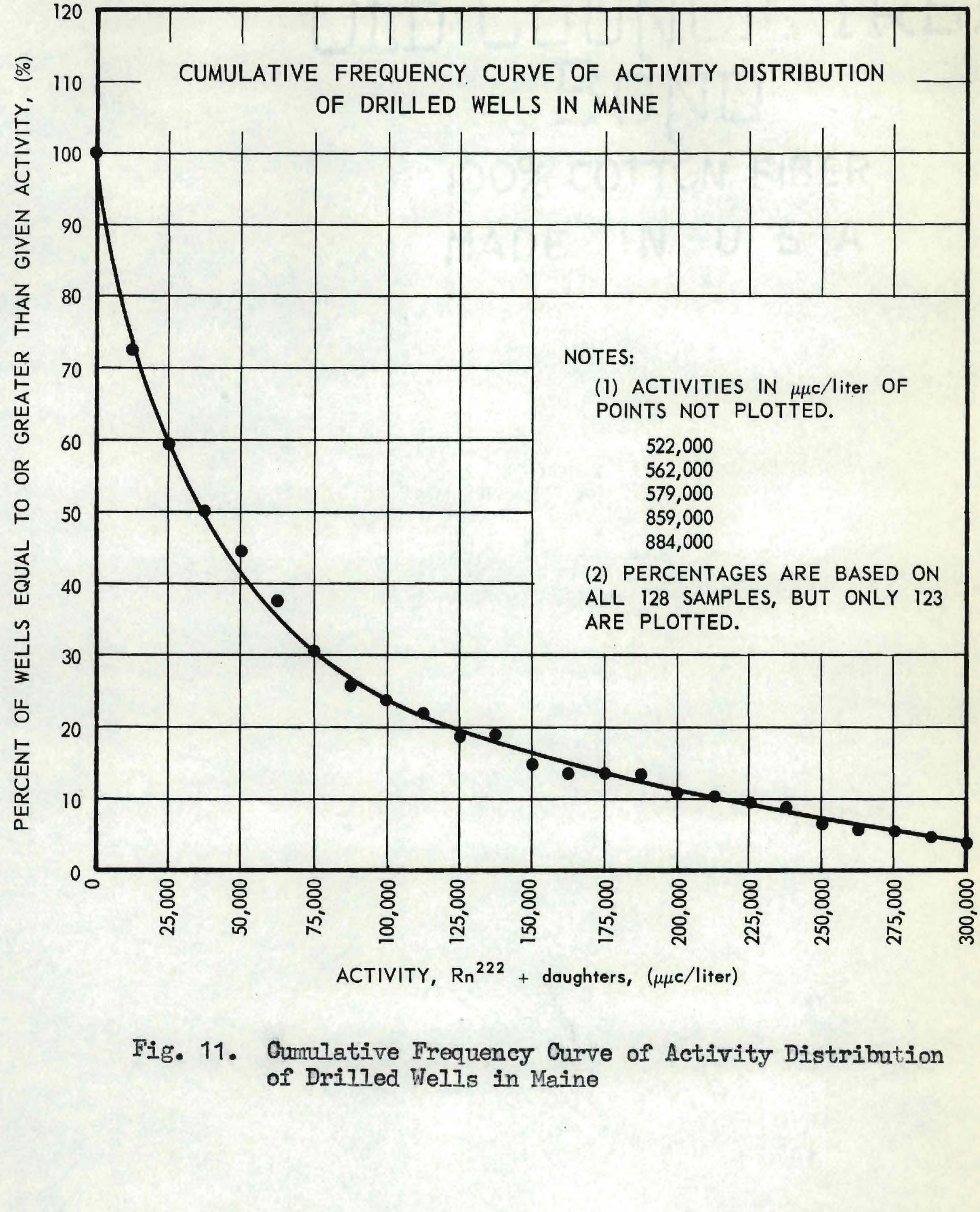

Fig. 11. Cumulative Frequency Curve of Activity Distribution of Drilled Wells in Maine

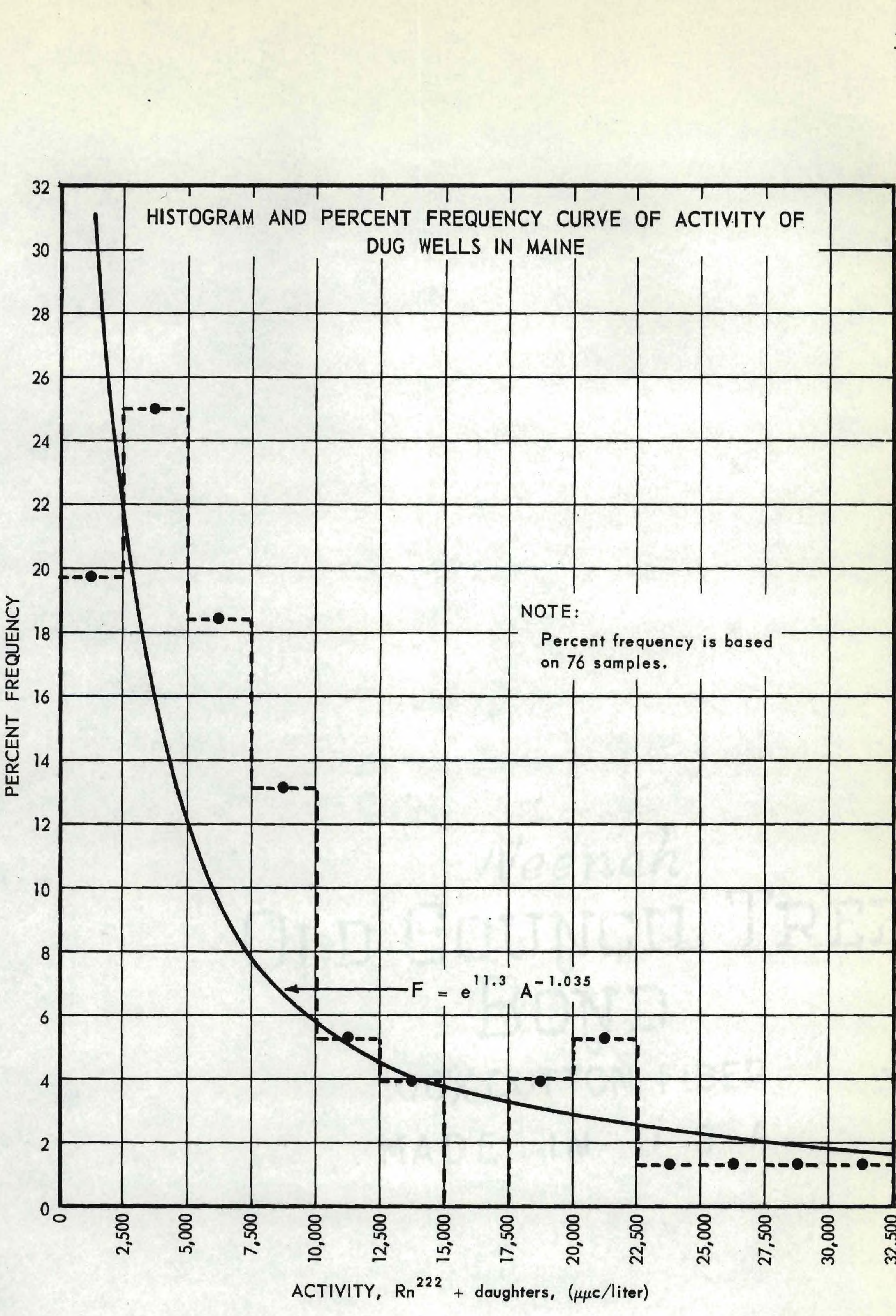

Fig. 12. Histogram and Percent Frequency Curve of Activity of Dug Wells in Maine

The cumulative frequency curve for radon activities from dug wells, presented in Figure 13, shows that approximately 84 per cent are above 2,000 $\mu\mu c/\ell$. Figure 13 also shows that:

90 per cent of all samples exceeded	1,250 $\mu\mu c/\ell$
50 per cent of all samples exceeded	5,500 $\mu\mu c/\ell$
10 per cent of all samples exceeded	18,500 $\mu\mu c/\ell$.

Histogram and per cent-frequency curves for all the drilled wells sampled in Maine and New Hampshire show results similar to those discussed above. The equation of best fit for the frequency curve was found to be:

$$F = e^{10.8} A^{-0.885} \tag{6}$$

with the units for F and A as previously defined.

From cumulative frequency calculations of the data from the 145 drilled wells in Maine and New Hampshire, it was found that approximately 99.3 per cent of the samples exceeded an activity of 2,000 $\mu\mu c/\ell$. Furthermore, the combined Maine and New Hampshire cumulative frequency distribution shows that:

90 per cent of all samples exceeded	4,000 $\mu\mu c/\ell$
50 per cent of all samples exceeded	35,000 $\mu\mu c/\ell$
10 per cent of all samples exceeded	225,000 $\mu\mu c/\ell$.

It would therefore appear that the radon activities of the samples obtained in Maine and New Hampshire were not significantly different from each other.

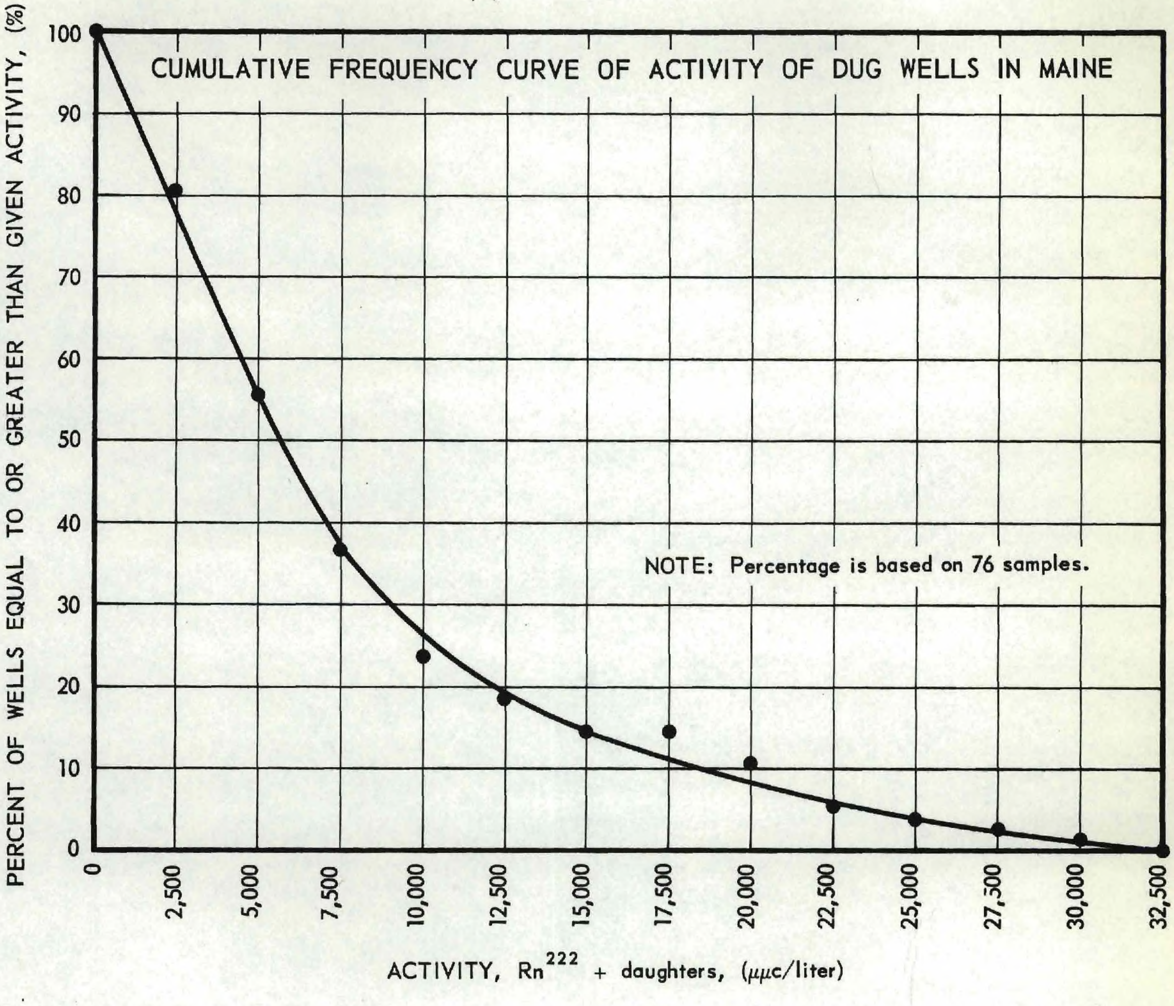

Fig. 13. Cumulative Frequency Curve of Activity of Dug Wells in Maine

The data were further subjected to statistical tests for skewness and kurtosis. By grouping the data, the activities of all 128 drilled wells in Maine were examined for normality. A high degree of skewness, $\alpha_3 = 3.7$, as well as a high degree of peakedness, $\alpha_4 = 19.9$, were noted. Similar analyses performed on the upgrouped New Hampshire data for the 17 drilled wells yielded values for $\alpha_3 = 2.97$ and $\alpha_4 = 11.3$ respectively.

Correlation Analyses of Results

To determine a functional relationship between radon activity and well depth, selected groups of data were plotted on arithmetic graph paper and subjected to correlation analyses.

Analyses According to States.--Initially, scatter diagrams for all the drilled and dug wells in Maine and New Hampshire were prepared with the activity plotted as the dependent variable and well depth as the independent variable as shown in Figures 14 and 15.

The results from linear correlation analyses of radon activities for Maine and New Hampshire considered separately and combined yielded low correlation coefficient values for all comparisons made as may be seen in Table 5.

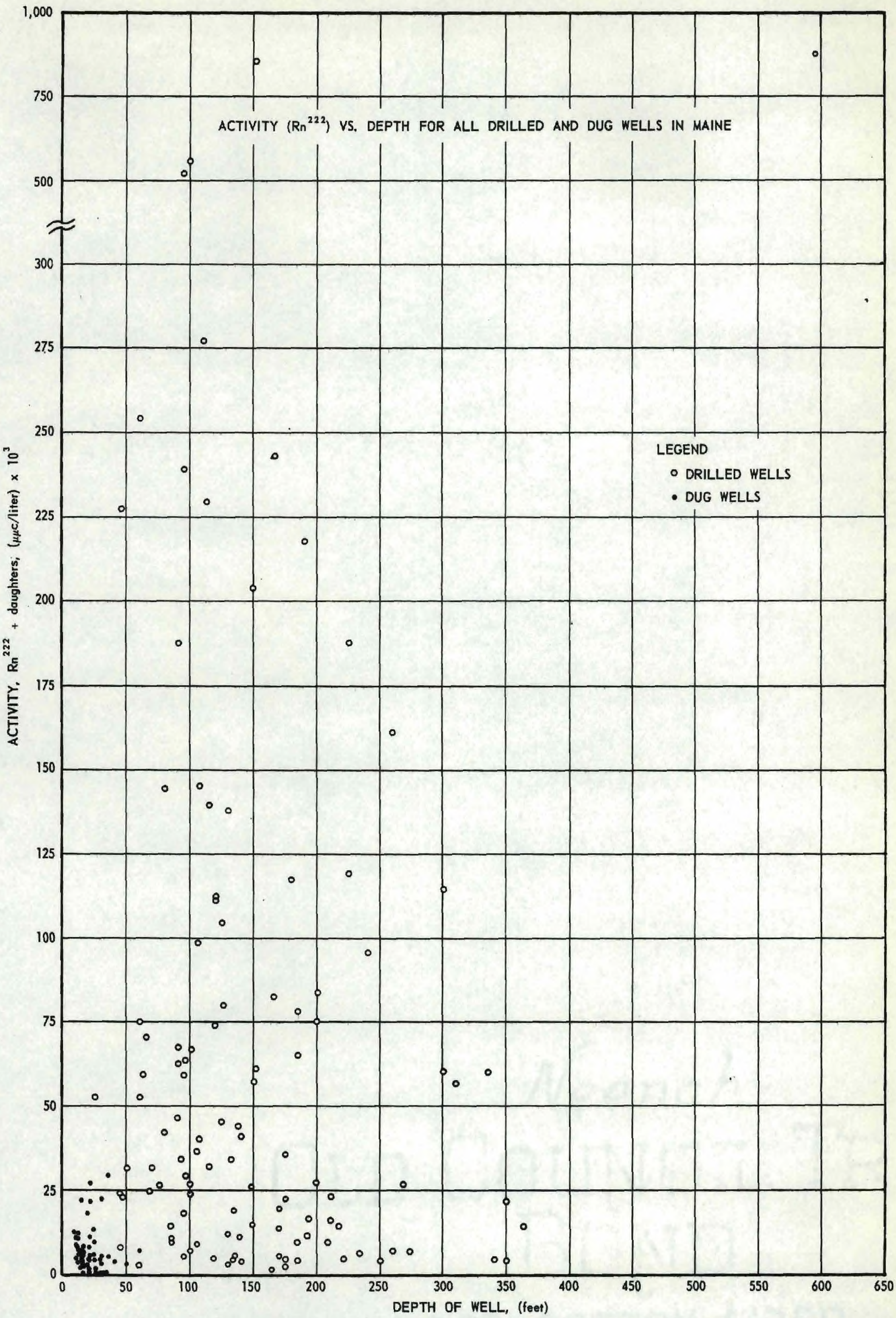

Fig. 14. Activity (Rn^{222}) vs. Depth for all Drilled and Dug Wells in Maine

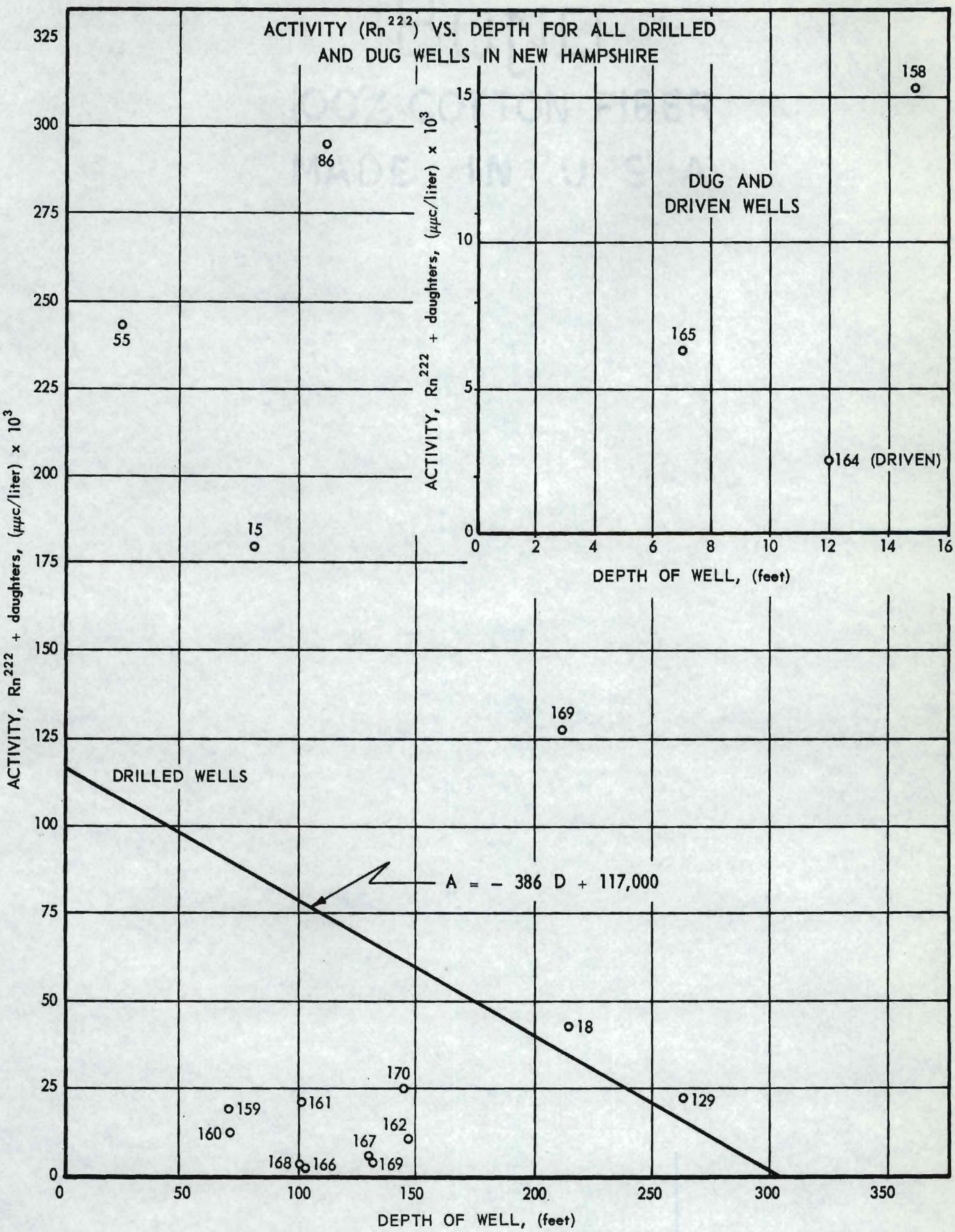

Fig. 15. Activity (Rn^{222}) vs. Depth for All Drilled and Dug Wells in New Hampshire

Table 5. Linear Correlation Coefficients for Radon Activity versus Well Depth

Maine	n*	r**	New Hampshire	n*	r**
Drilled wells only	112	0.23	Drilled wells only	15	0.25
Dug wells only	56	0.05	Sampled only 3 dug wells in New Hampshire		
Drilled and Dug wells	168	0.34	Drilled and other wells	19	0.03
Combined drilled wells, Maine and New Hampshire, n = 127, r = 0.18 .					

These results show that rather non-significant relationships exist between activity and depth of well.

<u>Analyses According to Geologic Zones in Maine</u>.--To define the geologic boundaries of the natural radioactivity, the samples from Maine were grouped accordingly. The 2,500 sq mi area sampled was divided into four geologic zones. These four zones, G-1 through G-4, were established in accordance with the geologic map reported by Billings (41). This map is reproduced as Figure 16. The following zones are distinguished on the map located at the end of the thesis and entitled "Approximate Location and Activity of Sampling Points in Maine and New Hampshire."

Zones G-1, G-2, G-3, and G-4 were defined as follows:

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*n = number of samples considered
**r = coefficient of linear correlation

FOSSIL LOCALITIES IN MASSACHUSETTS AND MAINE PERTINENT TO DATING SOME OF THE ROCKS IN NEW HAMPSHIRE. NUMBERS IN CIRCLES ARE FOSSIL LOCALITIES REFERRED TO BILLINGS.

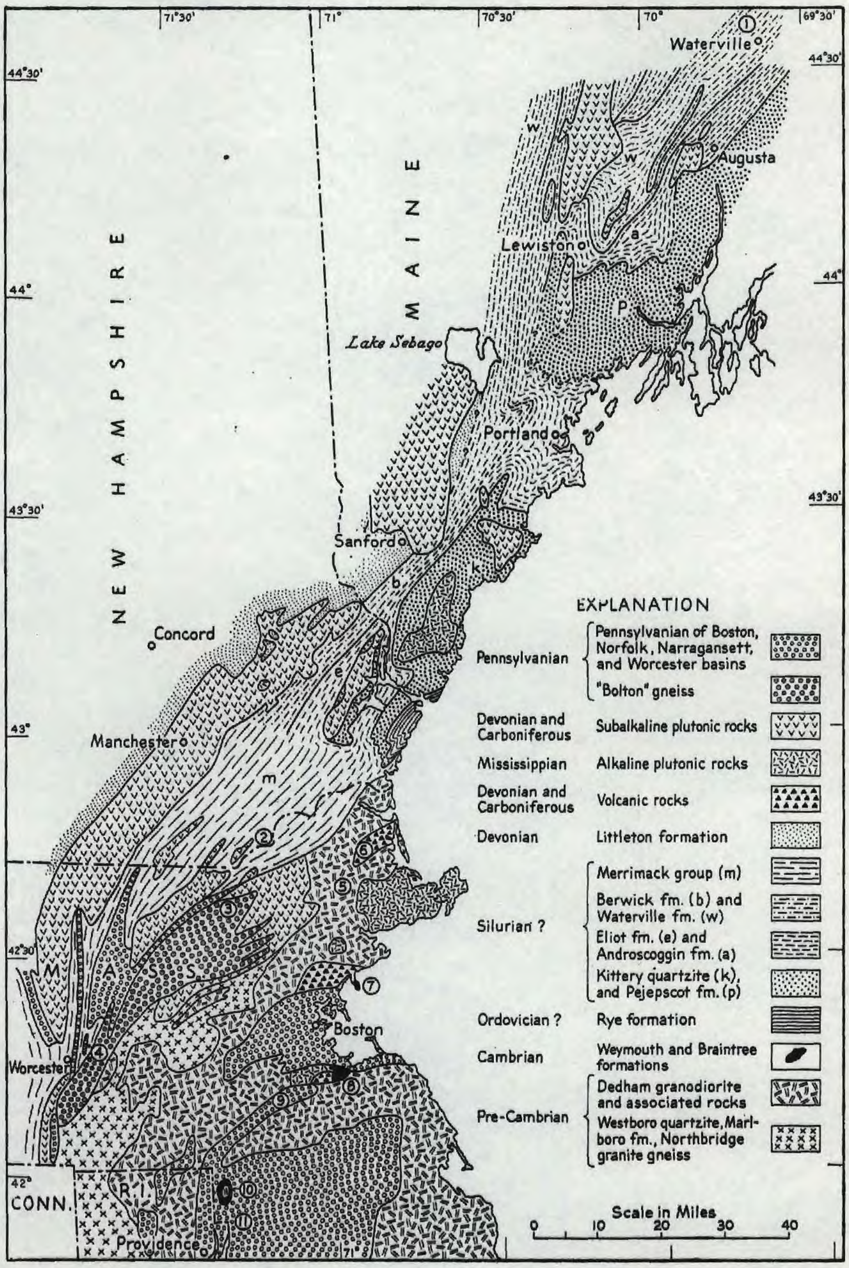

Fig. 16. Fossil Localities in Massachusetts and Maine

Zone G-1 The Waterville Formation (composed of calcareous and arenaceous shales, and slate with interbedded quartzite)

Zone G-2 The Androscoggin Formation (underlies the Waterville Formation; is composed of quartzite, mica shist, phyllite and calcareous phyllite; combined depth of Waterville and Androscoggin (Vassalboro) formations is 6,500 ft).

Zone G-3 The Pejepscot Formation (stated to be a metamorphosed Kittery Formation composed of gray quartzite, gray argillaceous quartzite, and gray slate; alternating in beds varing from a few inches to several feet thick. Elsewhere, large outcrops consist of only one lithologic type)

Zone G-4 Unknown Geology of Maine due West of G-1 (no specific geologic information available).

Figure 17 is a plot of radon activity versus depth of drilled wells in Zone G-1 only. There appears to be a trend of increasing activity with increased depth. The value for the coefficient of linear correlation, r, is 0.44. Although this value is not highly significant, it appears that some definite relationship exists between activity and depth within Zone G-1 which is stronger than that existing among all drilled wells in Maine ($r = 0.23$). The samples grouped under Zone G-1 include those obtained from Raymond Village and East Raymond, the area sampled most densely. The equation of best fit obtained by linear correlation is :

$$A = 779\ D + 32{,}300 \qquad (7)$$

where: A = activity of Radon-222 and daughters, $\mu\mu c/\ell$

D = depth of drilled well, feet.

Analyses of radon activity versus depth of drilled wells in zones G-2 and G-3 revealed that the activity decreased as depth increased in both cases. The coefficients of linear correlations of 0.41 for Zone G-2

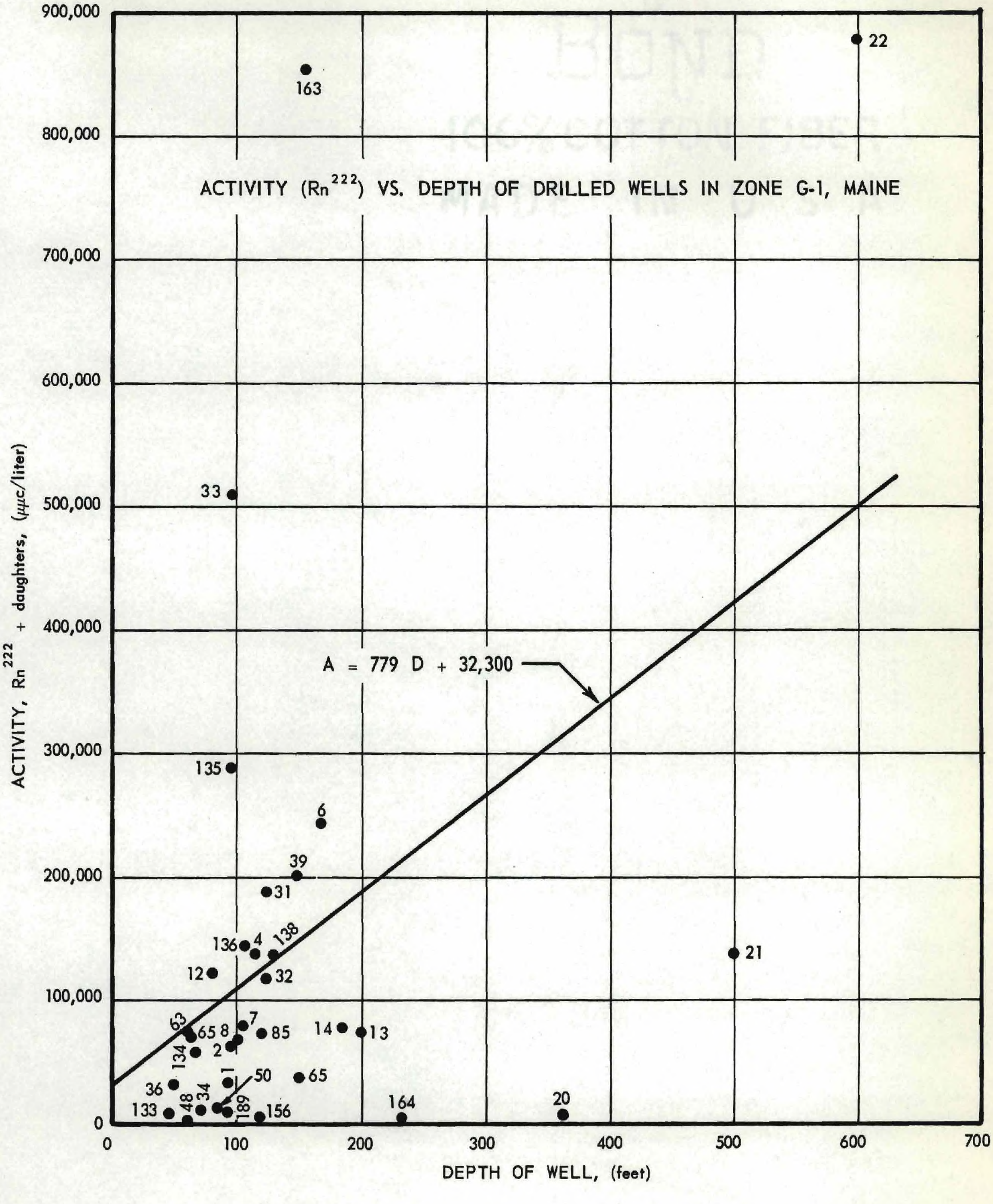

Fig. 17. Activity (Rn^{222}) vs. Depth of Drilled Wells in Zone G-1, Maine

and 0.19 for Zone G-3 are not highly significant. With these values, no definite conclusions can be drawn.

Analyses According to Geolographical Zones in Maine.--Sampling points had to be selected largely on a random basis since no complete geologic map for Maine was available. The emphasis, therefore, was placed on areas which had been previously studied by the Maine State Health Department or which were of special interest such as areas containing definite clusters of pegmatites and other mineral deposits or larger centers of population. Further correlation efforts were directed toward comparing radon activity with depth of drilled wells based on geographical zones in Maine. These zones, shown in Figure 18, were defined as:

Zone A - Raymond, Me. (three miles radius around the Dielectric Products Engineering Co., Inc., sampling point No. 22)

Zone B - Raymond, Me. (concentric area from three to six miles radius around No. 22)

Zone C - Mechanic Falls, Me. (six miles radius)

Zone D - South Paris, Maine (six miles radius)

The results from linear correlation analyses of the activities from drilled wells grouped according to these zones are shown in Table 6 (succeeding page).

In Zone A, the correlation of activity with depth tends to be significant and the activity increased with depth. The correlation of activity with depth for Zone B, based on only six samples, resulted in a value for r of 0.68. However, as seen from Equation (9), the activity decreased with increasing depth of well. The coefficient of correlation

BOUNDARIES OF ZONES A, B, C AND D AND AREAS I, II AND III, MAINE

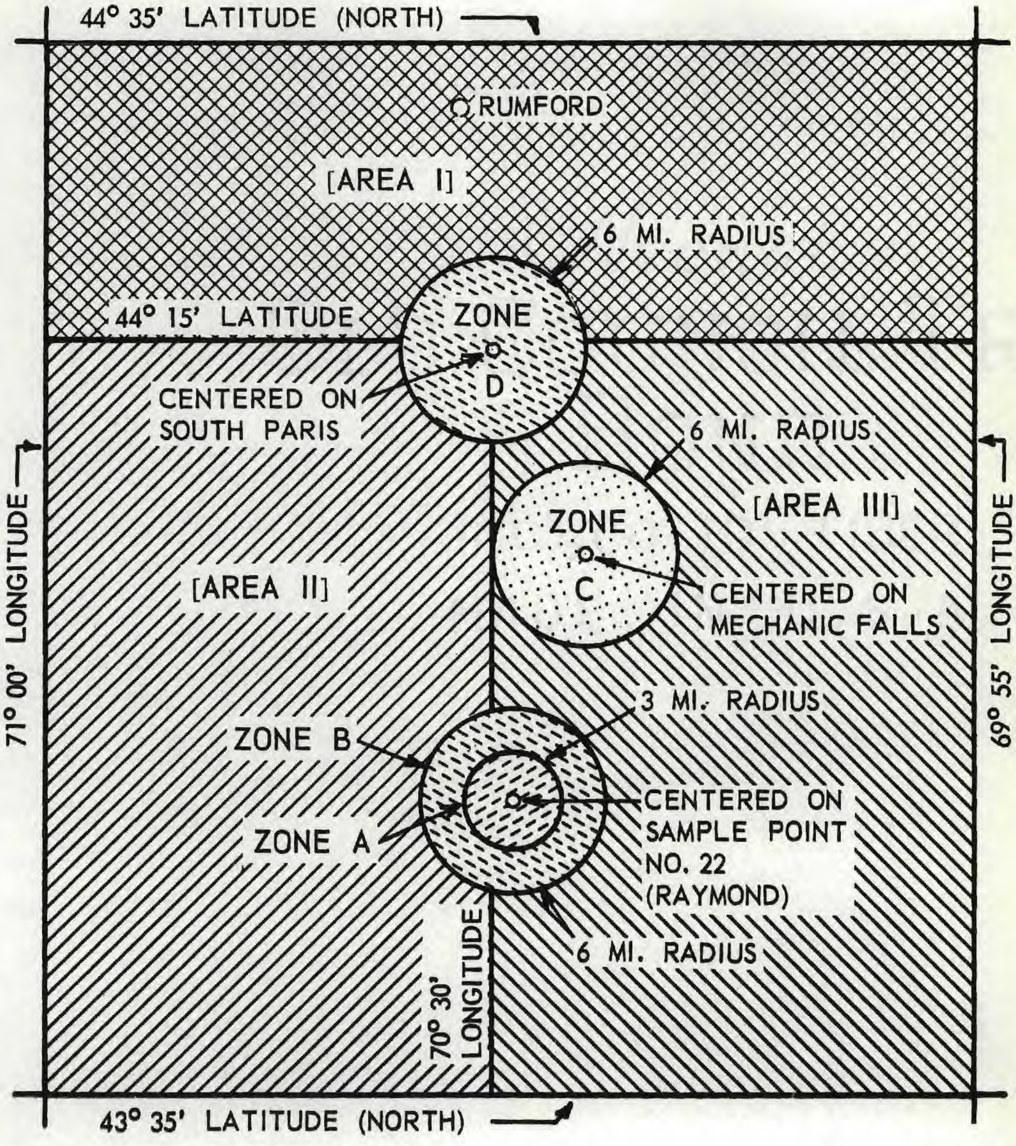

Fig. 18. Boundaries of Zones A, B, C and D and Areas I, II and III, Maine

of activity versus depth in Zones A + B is significant. The data are plotted in Figure 19. It may be observed that Equation (8) and (10) are quite similar for this densely sampled area and that activity increased with depth at approximately equal rates.

Table 6. Correlation of Radon Activity with Well Depth

Zone (s)	n	r	Equation of Best Fit	
A	22	0.41	A = 819 D + 5,410	(8)
B	6	0.68	A = -1,520 D + 216,000	(9)
A + B	28	0.56	A = 794 D + 6,400	(10)
C	13	0.08	A = 228 D + 126,000	(11)
D	10	0.70	A = 322 D + 14,300	(12)

The results from samples collected in and around Mechanic Falls, Zone C, exhibited considerable scatter when activity was plotted versus depth. This scatter is also reflected by the low value of r. However, in the South Paris area, Zone D, activity increased on the average with depth, as evidenced by Equation (12) which has a positive slope. The analysis of data obtained from Zone D resulted in a significant linear correlation.

A further breakdown of the 2,500 sq mi area of Maine sampled into three rather broad areas, excluding the zones discussed above, is also defined in Figure 18. Area I includes the area north of latitude $44^{\circ}\ 15'$ but excluding Zone D. Area II is west of longitude $70^{\circ}\ 30'$, exclusive of

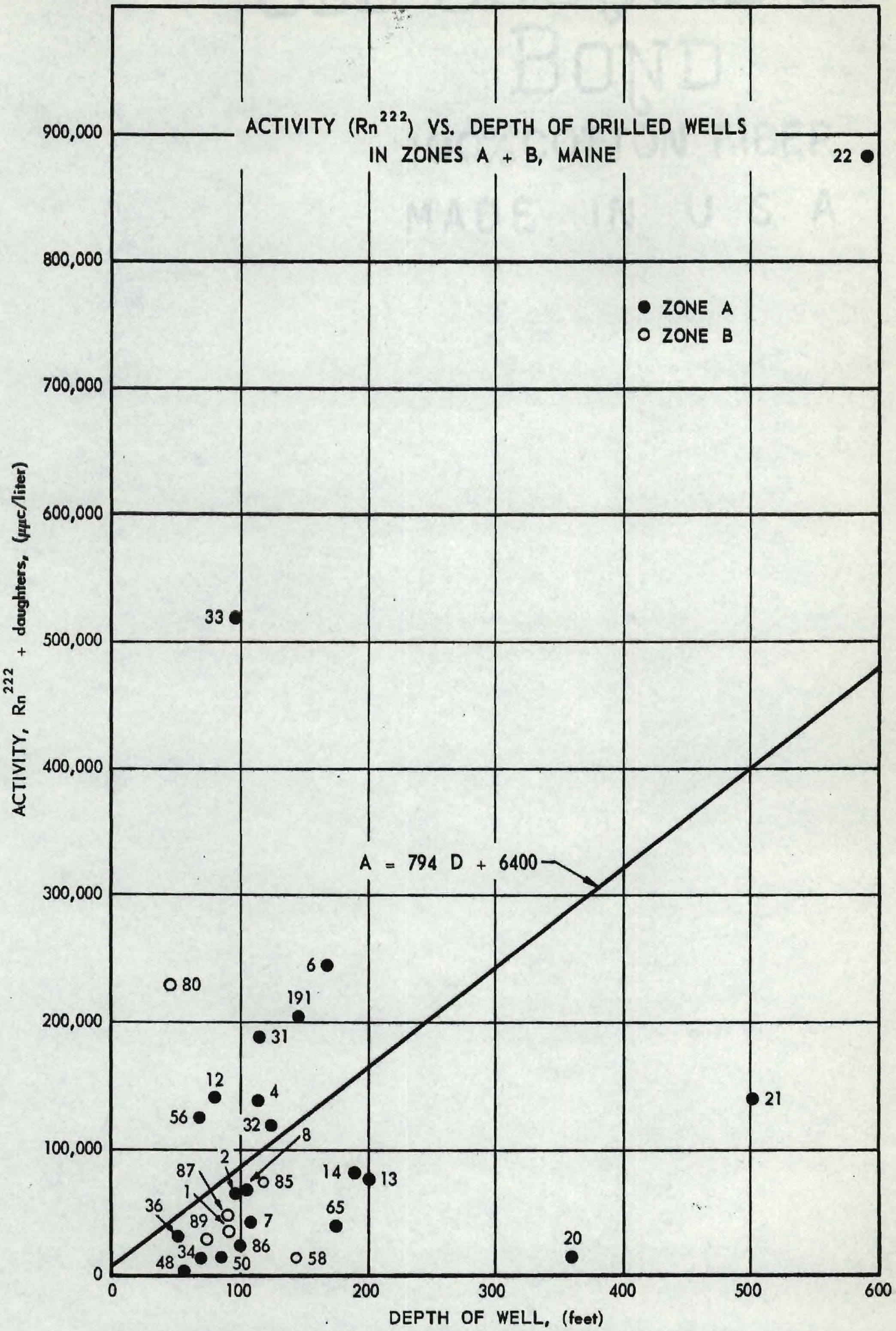

Fig. 19. Activity (Rn^{222}) vs. Depth of Drilled Wells in Zones A + B, Maine

Zones A, B, and D, and Area III is east of longitude 70° 30', exclusive of Zones A, B, C, and D. Little additional information could be obtained from plotting the activity versus depth for each of these areas. The coefficients of correlation for Areas I, II, and III were found to be 0.05, 0.17 and 0.25, respectively. The low values of r further indicate the large variance of the data when grouped according to these artificial boundaries.

As the area used as a basis for comparison was reduced in size, the degree of correlation improved. Figure 20 shows a plot of radon activity versus drilled depth for the communities of Raymond Village and East Raymond, Maine. The equation of best fit relating activity with depth is:

$$A = 1{,}810\ D - 79{,}000 \tag{13}$$

The coefficient of linear correlation with a value of 0.80 was found to be highly significant. It should be pointed out, however, that one sample, No. 33, was omitted from this analysis because of doubt as to the validity of depth data. The radon activities for the two communities were found to range between about 50,000 to 250,000 $\mu\mu c/\ell$ for well depths ranging from about 75 to 175 feet.

<u>Analyses According to Geologic Zones in New Hampshire</u>.--Similar analyses were performed with the data from drilled wells within and without the

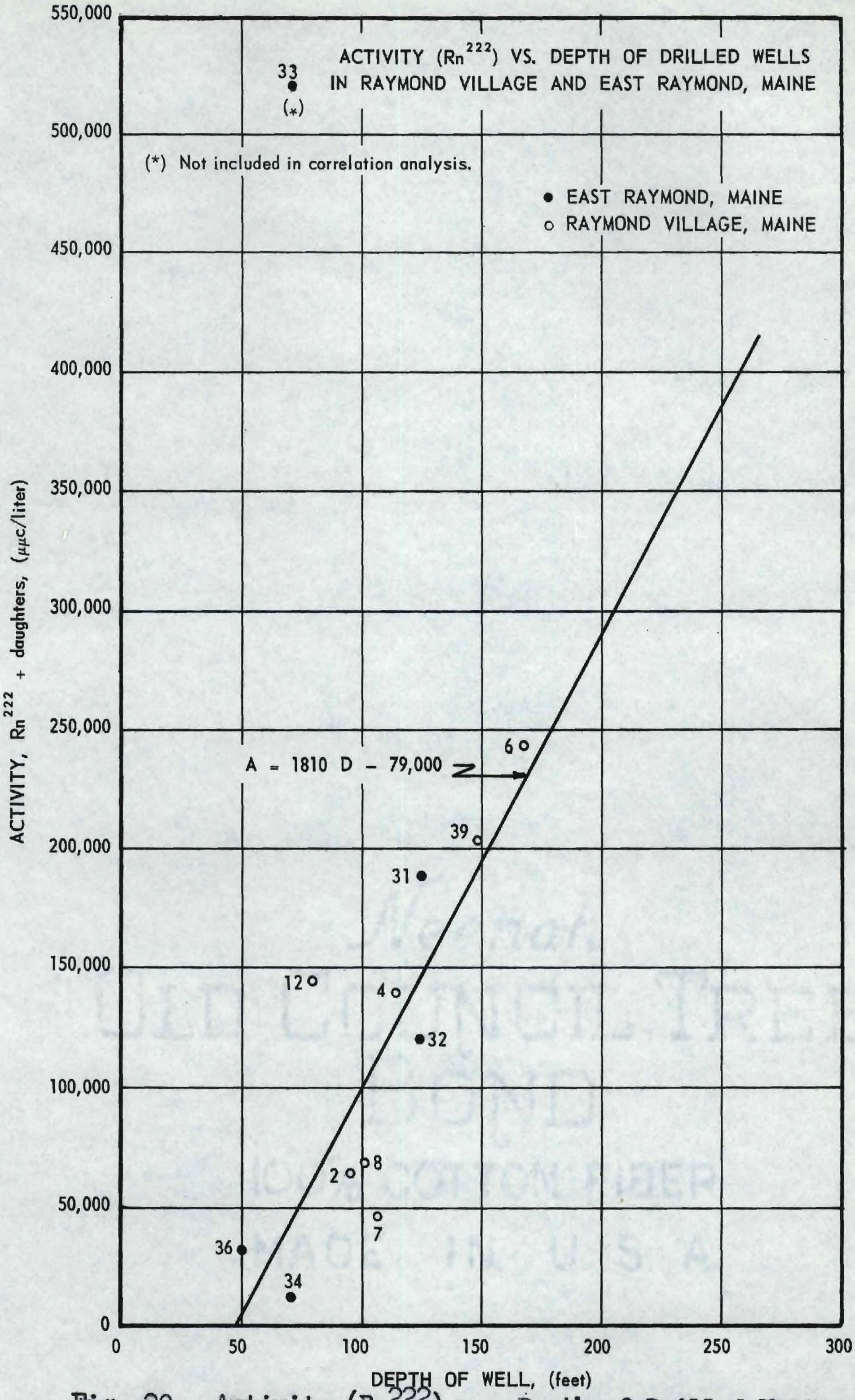

Fig. 20. Activity (Rn^{222}) vs. Depth of Drilled Wells in Raymond Village and East Raymond, Maine

Fitchburg Pluton *. The data from samples obtained within this geologic formation showed decreased activities with increased depth. The straight line of best fit is given by the equation:

$$A = -1{,}080\ D + 283{,}000\ . \tag{14}$$

Its coefficient of correlation of 0.77 is significant.

On the other hand, the plot of data from samples obtained outside of the Fitchburg Pluton showed increased activity with increased depth. The straight line of best fit is given by the equation:

$$A = 768\ D - 64{,}800\ . \tag{15}$$

The coefficient of linear correlation of 0.79 is also significant.

In both cases (within and without the Fitchburg Pluton) a significant relationship between activity and depth existed, but no real explanation can be offered for the opposite dependence between activity and depth.

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*Fitchburg Pluton: Detailed descriptions are available only for that portion of the Fitchburg Pluton around the Pawtuckaway Mountains in New Hampshire. The formation is composed of three major types of rock, although numerous pegmatites (perthite and quartz with small amounts of garnet, biotite, and muscovite) are present in bodies ranging in size from small dikes to intrusions 450 ft long and 50 ft wide. The first major type, quartz monzonite, is light to dark gray and is composed of potash feldspar some hornblende. The second, biotite-muscovite granite is white to light grey and is composed chiefly of potash feldspar, calcic oligoclase, and quartz. Microcline granite is the third major rock type and consists chiefly of pink microcline and quartz, with about 4 per cent each of biotite and muscovite and some calcic oligoclase. These three rock types are similar in several respects: (1) they are medium-grained to coarse-grained rocks; (2) foliation, although absent in some places, is elsewhere weak to strong; and (3) biotite is the principal dark mineral, although locally it may be accompained by hornblende or muscovite. (41).

Results of Correlation Analyses of Radium-226 in Maine and New Hampshire.-- A correlation analysis of the activity of Radium-226 versus depth from 28 drilled wells in Maine resulted in a value of r equal to 0.11, which is highly non-significant. The correlation of Radium-226 activity with depth from ten drilled wells in New Hampshire was considerably better with an r value of 0.64. The scatter diagram of the New Hampshire data and the equation of best fit are shown in Figure 21. It should be noted that the Radium-226 activity decreased with increased well depth.

Analyses for Differences of Statistical Significance

In addition to the correlation analyses described, further statistical tests were carried out in accordance with the breakdown of the 2,500 sq mi area in Maine, as indicated in Figure 18, into zones and areas, and into geologic Zones G-1 through G-4 as shown on the map which forms Appendix C and is entitled "Approximate Location and Activity of Sampling Points in Maine and New Hampshire". The results from these tests for statistical significance will be presented in the following order:

Zones A, B, C, and D in Maine

Areas I, II, and III in Maine

Zones versus Areas in Maine

Comparison of Geologic Zones in Maine

Dug and Drilled Wells in Maine

Drilled Wells in New Hampshire

Drilled Wells in Maine and New Hampshire

and are summarized in Table 7.

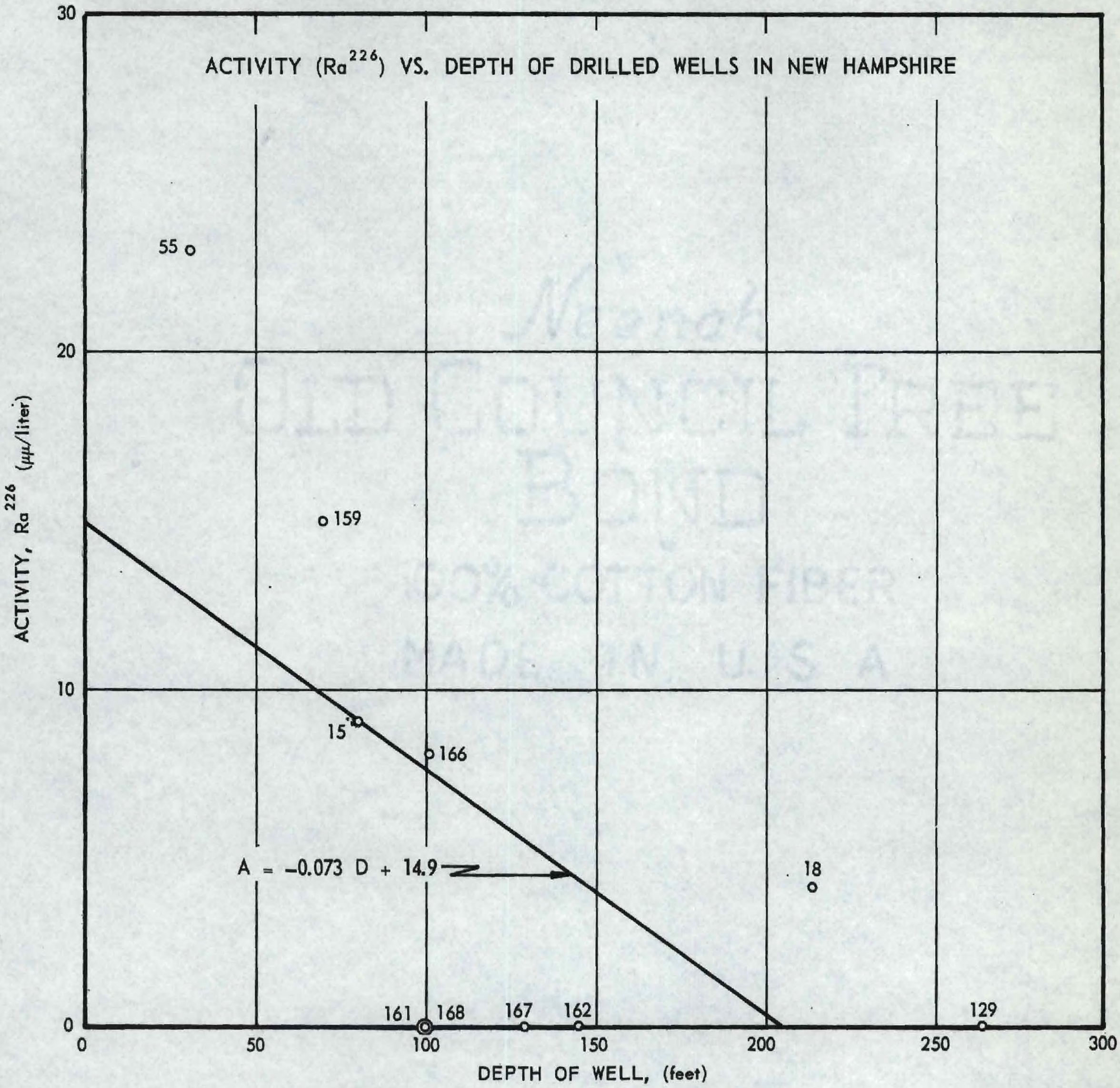

Fig. 21. Activity (Ra^{226}) vs. Depth of Drilled Wells in New Hampshire

Table 7. "t" and "F" Test Results from Drilled Wells in Maine

Zones and Areas Compared		"t" tests, Ref. (42) D.F.	"t"	P%	"F" tests, Ref. (43) D.F.$_2$ (*)	"F"	P%
Zone A	vs. Zone B	32	1.62	12	30	0.955	>5
Zone A	vs. Zone C	32	0.069	>90	38	0.015	>5
Zone A	vs. Zone D	34	1.71	10	33	1.407	>5
Zone A	vs. Area I	25	3.10	0.6	40	6.530	2
Zone A	vs. Area III	27	2.27	3.4	53	6.069	2
Zone A	vs. Me.-Zone A	27	1.82	7.5	126	7.205	0.9
Zone (A + B)	vs. Zone C	29	0.210	84	47	0.046	>5
Zone (A + B)	vs. Area I	32	3.35	0.3	47	5.993	2
Zone (A + B)	vs. Area III	40	2.30	2.9	60	5.022	4
Zone B	vs. Zone C	20	1.34	20	20	0.966	>5
Zone C	vs. Zone D	19	1.40	19	23	0.193	>5
Zone C	vs. Area I	14	2.51	3.5	30	7.422	1
Zone D	vs. Area I	9	2.28	5	25	8.380	0.9
Area I	vs. Area II	25	2.99	0.7	39	6.392	2
Area II	vs. Area III	38	1.45	16	52	2.371	>5
Area I	vs. Area III	28	2.81	0.9	45	4.936	4
Zone (G-1)	vs. Zone (G-2)	43	1.80	8	47	1.876	>5
Zone (G-2)	vs. Zone (G-3)	19	1.44	16	33	2.659	>5
Zone (G-1)	vs. Zone (G-3)	48	3.47	0.1	56	8.178	0.8
Zone (G-1)	Vs. Zone (G-4)	71	2.45	1.8	91	6.409	1
Zone (G-2)	vs. Zone (G-4)	34	0.589	55	68	1.773	>5
Zone (G-3)	vs. Zone (G-4)	79	0.870	39	77	0.392	>5
Zones (G-1,2)	vs. Zones (G-3,4)	94	2.80	0.9	126	8.286	0.7
Me.	vs. N.H.	17	0.887	39	143	1.920	>5
NH-1	vs. NH-2	7	2.08	8	15	4.748	5
Granitic	vs. Metamorphic	119	1.67	10	126	1.736	>5
Me. Drilled	vs. Me. Dug	129	6.10	<0.1	200	21.02	<0.1

(*) D.F.$_1$ = 1 for all cases.

Zones A, B, C, and D in Maine.--Using Student's "t" distribution and the "t" test for significance * between the radon activities from drilled wells in Zones A, B, C, and D of Maine, it was found that, if the 90 per cent level of significance is adopted, a difference equal to or greater than that found when comparing Zone A with Zone B and Zone A with Zone D would occur on the average 12 per cent and 10 per cent of the time, respectively. This indicates a borderline significance for real differences in the respective activities between Zones A and B and between Zones A and D. Zone A has a greater average than Zone B or Zone D as may be seen in Table 8.

A similar comparison of the average difference between Zones A and C resulted in a probability greater than 90 per cent due to chance factors alone, which is highly non-significant. Therefore, no real difference between the activities in Zone A and C is indicated. Comparison of Zone B with Zone C and Zone D produced similar non-significant results as shown in Table 7.

The area included by Zones A plus B represents the most intensively studied section of Maine, therefore, the activities were compared with those in Zone C. No significant difference was found (probability = 84 per cent) between these zones.

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*Test of the hypothesis that the means of two normal distributions are equal, assuming that the standard deviations are unknown and not necessarily equal (42).

Table 8. Compilation of Data by Selected Groups

State	Area	Type of Well	Rn-222 + daughters through Po-214: No. of Samples	Activity in μμc/ℓ: Min.	Ave.	Max.	Ra-226: No. of Samples	Activity in μμc/ℓ: Min.	Ave.	Max.
Me.	All	Dug, Drl., Spg.	228	0	53,700	884,000	55	0	65	730
N.H.	All	Dug, Drl., Spg.	26	2,510	101,000	1,130,000	21	0	4.8	23
Me.	All	Drilled	128	1,120	87,600	884,000	33	0	66	440
Me.	All	Dug	76	0	7,870	31,700	19	0	73	730
Me.	All	Springs	18	0	18,800	113,000	2	0	1.0	2.0
Me.	Zone A	Drilled	25	2,780	157,000	884,000	4	0	38	87
Me.	Zone A	Dug	13	3,570	11,400	29,200	4	0	19	77
Me.	Zone B	Drilled	7	14,400	69,800	228,000	0			
Me.	Zone B	Dug	6	3,350	15,500	27,200	0			
Me.	Zone B	Springs	3	21,700	27,400	31,500	0			
Me.	Zone A+B	Drilled	32	2,780	138,000	884,000	4	0	38	87
Me.	Zone A+B	Dug	19	3,350	12,700	29,200	4	0	19	77
Me.	Zone A+B	Springs	3	21,700	27,400	31,500	0			
Me.	Zone C	Drilled	15	2,760	152,000	859,000	8	0	160	440
Me.	Zone D	Drilled	10	5,080	68,300	191,000	4	0	91	340
Me.	Zone D	Dug	2	4,840	6,670	8,480	2	0	0	0
Me.	Area I	Drilled	17	1,120	13,500	82,400	9	0	23	95
Me.	Area I	Dug	21	0	4,810	18,300	11	0	77	730
Me.	Area I	Springs	6	0	4,040	13,300	2	0	1.0	2.0
Me.	Area II	Drilled	24	7,140	88,400	562,000	6	0	29	160

Table 8. Compilation of Data by Selected Groups (Continued)

State	Area	Type of Well	Rn-222 + daughters through Po-214: No. of Samples	Activity in μμc/ℓ: Min.	Ave.	Max.	Ra-226: No. of Samples	Activity in μμc/ℓ: Min.	Ave.	Max.
Me.	Area II	Dug	20	402	7,700	23,900	3			
Me.	Area II	Springs	7	1,820	11,200	36,200	0			
Me.	Area III	Drilled	30	2,450	49,100	278,000	0			
Me.	Area III	Dug	14	1,120	6,520	31,700	1	0	0	0
Me.	Area III	Springs	2	41,700	76,900	113,000	1	2.0	2.0	2.0
Me.	Zone G-1	Drilled	36	2,780	152,000	884,000	9	0	75	400
Me.	Zone G-1	Dug	17	1,350	10,400	29,200	5	0	15	77
Me.	Zone G-2	Drilled	13	2,760	83,800	230,000	1	130	130	130
Me.	Zone G-2	Dug	9	1,120	11,800	27,200	0			
Me.	Zone G-3	Drilled	22	2,450	43,500	278,000	0			
Me.	Zone G-3	Dug	6	1,240	12,500	31,700	0			
Me.	Meta.	Drilled	44	3,510	58,200	256,000	10	0	71	440
Me.	Granitic	Drilled	84	1,120	93,300	884,000	14	0	63	400
N.H.	All	Drilled	17	2,560	142,000	1,130,000	12	0	6.9	23
N.H.	All	Dug	3	6,180	30,100	68,800	3	0	4.1	12
N.H.	All	Springs	1	6,130	6,130	6,130	1	5.7	5.7	5.7
N.H.	Grafton	All Wells	3	2,510	4,940	6,180	3	0	1.9	5.7
N.H.	Dover	All Wells	4	3,550	6,780	9,350	4	0	0.1	0.4
N.H.	In Fitch	Drilled	8	10,700	284,000	1,130,000	7	0	8.4	23
N.H.	Out Fitch	Drilled	9	2,560	25,500	136,000	5	0	4.6	15

As an alternate method, an analysis of variance using the "F" test (43) was performed to compare the activities in Zones A, B, C, and D. Degrees of freedom, values of "F", and resulting probabilities for all comparions between those zones are shown in Table 7. No significant differences between zones were found. The "F" test is weaker than the "t" test for the analysis of extremely skewed data of this type (See page 41) , therefore, differences in results obtained from the two analyses may be expected. However, the less precise results of the "F" test may be used here to support the "t" conclusions.

Areas I, II, and III in Maine.--Based on the "t" test, the probability that differences between Area I and Area II and between Area I and Area III are as great or greater than obtained was found to be only 0.7 per cent and 0.9 per cent, respectively, due to chance factors alone. The average activities for Areas II and III were found to be considerably greater than the average for Area I, and a further comparison indicates that Areas II and III are not significantly different. Results of an "F" test comparing the Areas compare favorably with those of the "t" test.

Zones Versus Areas in Maine.--Of all the comparisons between zones and areas, only the six results showing a significant difference in average activities are shown in Table 7. All other comparisons yielded non-significant results.

When average activities were compared statistically using the "t" test, Zone A was found to have a significantly higher level of activity than that found in Area I and Area III. The average radon activity for Zone A was found to be 157,000 $\mu\mu c/\ell$, while those of Areas I and III were only 13,500 $\mu\mu c/\ell$ and 49,100 $\mu\mu c/\ell$, respectively.

The probabilities that the differences between the activities of Zone A + B and Area I and between Zone A + B and Area II would occur by chance factors alone were found to be 0.3 and 2.9 per cent, respectively. This indicated a real difference in activities between Zone A + B and Area I and Area III.

Area I was found to have a significantly lower average activity than Zones C and D. The average activity of Area I was found to have an average radon activity of only 13,500 $\mu\mu c/\ell$ while those of Zones C and D were 152,000 $\mu\mu c/\ell$ and 68,300 $\mu\mu c/\ell$, respectively.

Results of "F" tests comparing the same zones with areas as for the "t" test just discussed yielded similar results of statistical significance in all cases.

Comparison of Geologic Zones in Maine.--Further tests for statistical significance were based on the available geologic information on Maine. The 2,500 sq mi area was divided into four geologic zones as defined in the preceeding section and outlined on the map entitled "Approximate Location and Activity of Sampling Points in Maine and New Hampshire."

Significant differences in average activities were found to exist between: (1) Zone G-1 and Zone G-3, (2) Zone G-1 and Zone G-4, and (3) Zones G-1 plus G-2 and Zones G-3 plus G-4. Borderline significance was found to exist between Zone G-1 and Zone G-2 with probability equal to eight per cent. All other comparisons between geologic zones in Maine yielded non-significant results.

The same results as those found by the application of the "t" test were also obtained from the "F" test with only one exception. The "F" test did not show a significant difference between Zones G-1 and G-2.

In addition to these tests for significance the Chi-square distribution was applied to test these data. The conclusions reached were quite similar to those obtained with the "t" and "F" tests and confirm the significant differences between Zones G-1 and G-3 and between Zones G-1 and G-4. When a comparison of agreement between the observed and the expected number of samples per activity level from Zones G-1, G-2, G-3 and G-4 was made, a probability of 1.8 per cent that activity distribution is independent of geologic zone was obtained. This indicates that a significant difference in activities exists between these zones. Table 9 shows a typical Chi-square analysis and the results obtained from the Chi-square tests performed.

Comparisons by statistical methods of the activities of drilled wells in grantic rocks and those in metamorphic rocks in Maine show borderline significance for the "t" test results with a probability of 10 per cent and non-significance for the "F" test results. A description of these geologic zones is given by Cameron, et al. (44) and shown in Figure 22.

Table 9. Typical Chi-Square Test
Comparison of Activity Distribution Between Geologic Zones G-1, G-2, G-3, G-4

Activity Level Rn-222+dghtrs. ($\mu\mu c/\ell$)	Number of Occurrences				
	Geologic Zones				Totals Per Activity
	G-1	G-2	G-3	G-4	
0 - 14,900	8	3	13	29	53
15,000 - 44,900	11	5	6	16	38
45,000 - 124,000	4	2	2	7	15
125,000 - above	13	3	1	5	22
Total per Area	36	13	22	57	N=128

$$\chi^2 = \sum_{i=1}^{r} \sum_{j=1}^{c} \frac{(O_{ij} - E_{ij})^2}{E_{ij}} = 20.052$$

D.F. = (r-1) (c-1) = 9: P = 1.8%

where: D.F. = degrees of freedom; r = Number of rows; c = Number of columns
O_{ij} = observed number of samples within a given activity level and geologic zone
E_{ij} = expected number of samples within a given activity level and geologic zone
$E_{ij} = \frac{(n)(m)}{N}$
n = number of occurrences per geologic zone
m = number of occurrences per activity level
N = total number of occurrences considered in the test
P = probability that activity distribution is independent of geologic zone

Summary of All Chi-Square Test Results

Zones Compared	Number of Samples	D.F.	Chi-Square (χ^2)	Probability (%)
G-1 vs. G-1 thru G-4	128	9	20.052	1.8
G-1 vs. G-2	49	3	0.825	84
G-1 vs. G-3	58	3	13.806	0.35
G-1 vs. G-4	93	3	13.474	0.40
G-2 vs. G-3	35	3	5.381	15
G-2 vs. G-4	70	3	4.145	25
G-3 vs. G-4	79	3	0.720	87

GENERALIZED GEOLOGIC MAP OF PART OF SOUTHWESTERN MAINE SHOWING THE DISTRIBUTION OF METAMORPHIC ROCKS, GRANITES, PEGMATITE QUARRIES AND PROSPECTS. OUTLINES OF AREAS OF GRANITIC ROCKS FROM ARTHUR KEITH, 1935.

(Metamorphic and Granitic Rock Zones Defined)

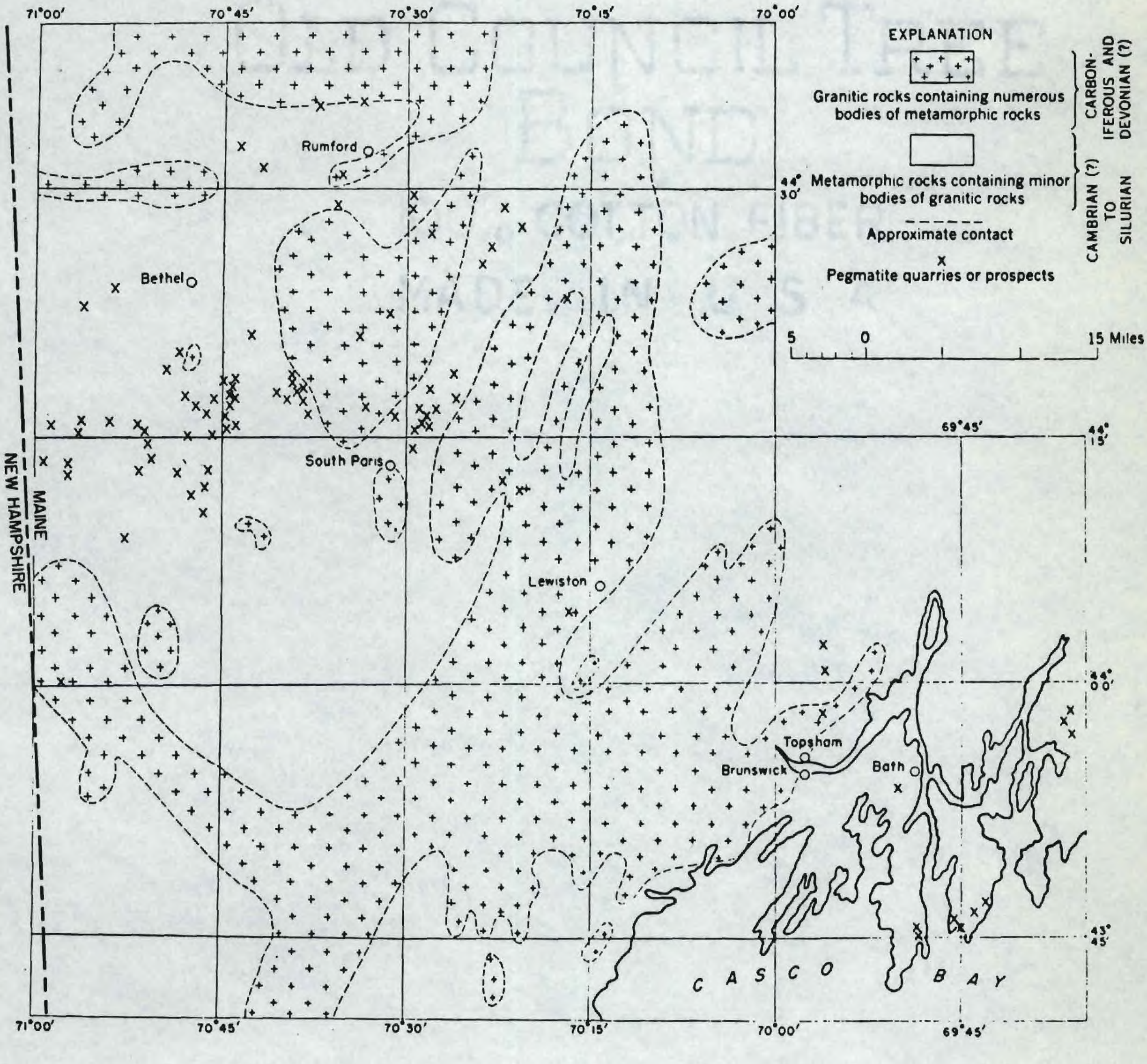

Fig. 22. Generalized Geologic Map of Part of Southwestern Maine

Dug and Drilled Wells in Maine.--Thus far, all the comparisons discussed have been confined to the drilled wells in Maine only. However, the dug wells in Maine were analyzed similarly.

The results from both "t" and "F" tests comparing the average radon activity of all the 76 dug wells with that of all the 128 drilled wells in Maine disprove the hypothesis that there is no real difference between them. In both cases, the results show that less than 0.1 per cent of the time could a difference as great or greater than found between these two types of wells be expected due to chance factors alone. The average radon activity for the dug wells was 7,870 $\mu\mu c/\ell$ compared with the average activity of 87,600 $\mu\mu c/\ell$ for drilled wells.

Results of "F" tests performed on the activities obtained from dug wells in Maine show several significant differences between selected areas. Most of the significant differences were found for the same groupings of areas as were found significant for the drilled wells. The results are summarized in Table 10. Significant differences in average activities were found to exist between:

Zone A	and	Area I
Zone A + B	and	Area I
Zones A + B	and	Remainder of the 2,500 sq mi area
Zones G-1 + G-2 + G-3	and	Zone G-4
Zone G-1	and	Zone G-4
Zone G-3	and	Zone G-4 .

Table 10. "F" Test Results from Dug Wells in Maine

Zones and Areas Compared*		D.F.$_2$**	"F"	P%
Zone A	vs. Area I	32	8.296	0.75
Zone A	vs. Area II	31	1.997	10
Zone A	vs. Area III	25	3.034	10
Zones A + B	vs. Area I	38	9.734	0.4
Zones A + B	vs. Area II	37	4.251	5
Zones A + B	vs. Area III	31	5.069	4
Zones A + B	vs. (Me.-A + B)	74	12.33	0.1
Zone G-1	vs. Zone G-3	21	1	10
Zones G-1,2,3	vs. Zone G-4	74	13.40	0.1
Zone G-1	vs. Zone G-2	24	1	10
Zone G-2	vs. Zone G-3	13	1	10
Zone G-1	vs. Zone G-4	59	7.630	0.9
Zone G-2	vs. Zone G-4	51	1.035	10
Zone G-3	vs. Zone G-4	48	8.433	0.8

*All "F" test results between Areas I, II, and III were non-significant.

**D.F.$_1$ = 1 in all cases.

Drilled Wells in New Hampshire.--The analyses of the 17 drilled wells in New Hampshire were separated into two groups as follows:

NH - 1	Within Fitchburg Pluton*
NH - 2	Without Fitchburg Pluton.

From a comparison of the areas within and without the plutonic formation, a significant difference between their average activities was found. Based on the "t" test, a difference as great or greater than that observed can occur due to chance alone only eight per cent of the time. According to the "F" test the probability value is only five per cent. Therefore, there appears to exist a significant difference between the activities in wells from within the Fitchburg Pluton and those from wells located to the east and to the west of this formation.

Drilled Wells in Maine and New Hampshire.--Both "t" and "F" test analyses of radon activities from all the drilled wells were performed. These analyses include 128 drilled wells from Maine and 17 from New Hampshire. In both tests, the null hypothesis that no real difference between the activity in drilled wells in these two New England states exists was not significantly disproven. A probability of 39 per cent was obtained from the "F" test. Therefore, from the samples analyzed, there appears to be no real difference in the concentrations of radon activity in water supplies from drilled wells in Maine and those in New Hampshire. However, this does not preclude the occurrence of areas with significantly high

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*The geology of the Ftichburg Pluton was described on page 54 .

activities in both states. Such areas have been shown to exist as previously discussed.

From Figure 16, it may be seen that the Fitchburg Pluton (sub-alkaline, plutonic rocks) extends northeasterly, with interruptions, into Maine. As a study of the continunity of the Fitchburg Pluton from New Hampshire into Maine, the available radon activities from drilled wells in the Pluton in both states were compared. Only the activities from two drilled wells in Maine, both in the section of the Fitchburg Pluton just south of Lake Sebago, were available (sampling points Nos. 95 and 102). Their radon activities were 7,140 and 562,000 $\mu\mu c/\ell$, respectively. Their average activity of 284,600 $\mu\mu c/\ell$ compares favorably with the average of the activities from eight drilled wells within the pluton in New Hampshire of 284,000 $\mu\mu c/\ell$. The close agreement between these values is considered merely a coincidence rather than proof that the activity from drilled wells in the pluton is everywhere the same. However, the comparison appears to indicate that there is a continuing high level of activity within the pluton and continuing outside the borders of New Hampshire. Further work to pursue similar studies south of the Nottingham-Deerfield, New Hampshire, area should prove interesting.

Another indication that the high level of activity may be associated with the relatively narrow band of formation(s) following the outline of the Fitchburg Pluton in New Hampshire and Zone G-1 in Maine was obtained from a "t" test. Comparing the activities of drilled wells from NH - 1 (within the Fitchburg Pluton) and Zone G-1 (Waterville

Formation) with those from all other geologic zones, (including NH - 2, G-2, G-3 and G-4), the average difference in activities was found to occur due to chance alone less than 0.1 per cent of the time. This extremely small probability shows that a very real difference exists and that activities from NH-1 and Zone G-1 were significantly greater than from the other areas.

Activity Distribution Based on Quadrant Analysis

Since the density distribution of samples over the State of Maine and per geographical quadrant (15 minutes by 15 minutes) was not adequate for purely statistical purposes, a different approach to the problem was devised. To obtain a better insight into the geographical distribution of activities, the 2,500 sq mi area was divided into small, five-minute by five-minute quadrants. The exact divisions, the number of samples per five-minute quadrant, and the average activity level per quadrant for drilled wells in Maine are indicated in Figure 23. Superimposed are the contours separating granitic and metamorphic rocks according to the generalized geologic map as shown in Figure 22. The cross-hatched areas contain the wells with the maximum levels of activity, or average radon concentrations of 150,000 $\mu\mu c/\ell$ and above. It is interesting to note from Figure 23 that all five of these areas are within the granitic rock formation. It should also be pointed out that four out of five of these subquadrants are within Zones G-1 and G-2, previously shown to contain significant concentrations of activity.

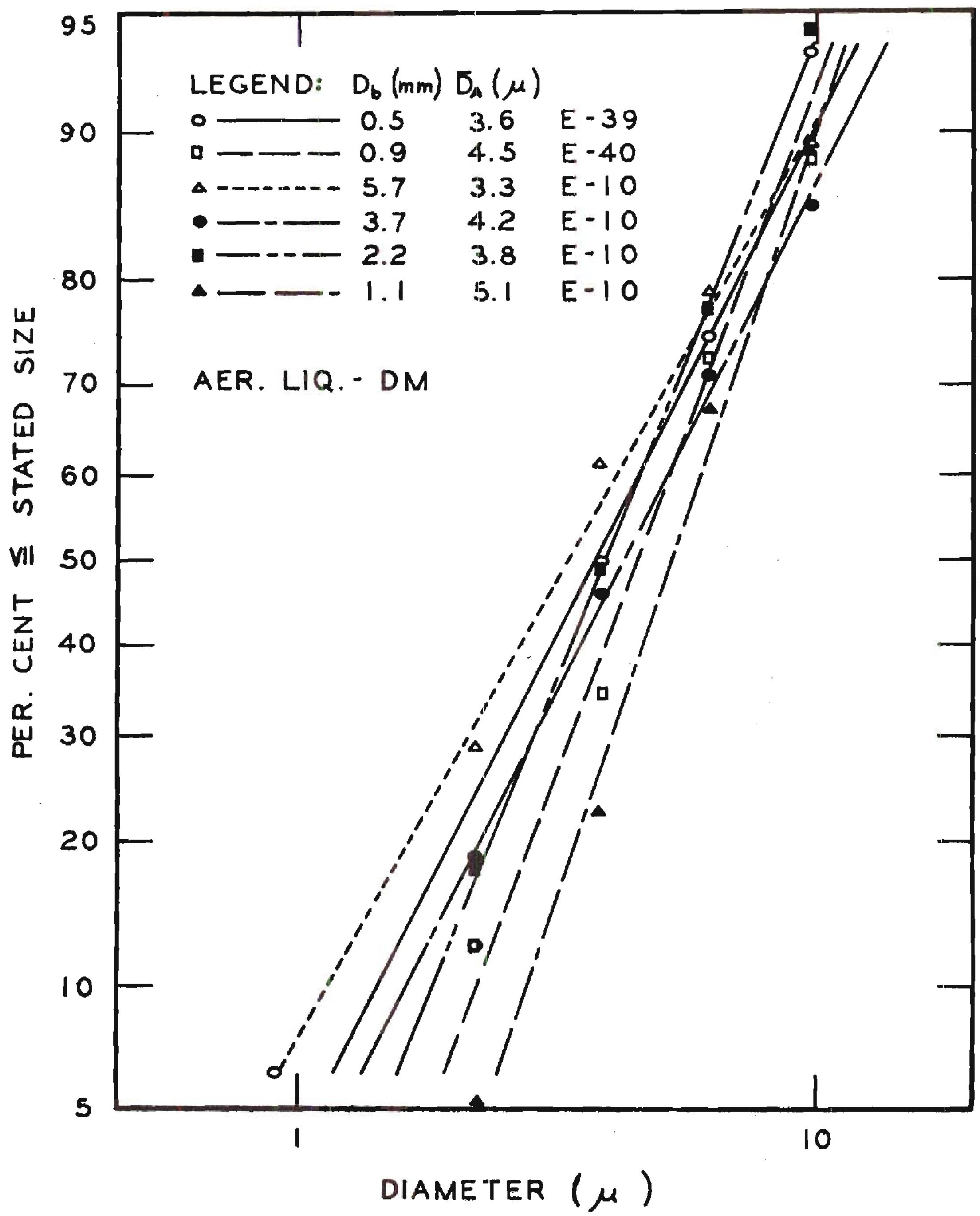


Figure 18. Log Probability Plot of Bioparticle Size Distributions for 0.5, 0.9, 1.1, 2.2, 3.7, and 5.7 mm Bubbles

A profile map with the maximum activities shown as peaks, obtained by cutting longitudinally through sections D through I, is shown as Figure 24. Connecting the average peak values, referred to the abscissa of each longitudinal section (from D through I), for each section with those of the next, going from west to east, results in the dotted "trend lines" in Figure 24. The maximum average peaks are connected by the heavier dotted line in the center, while the secondary peaks to the east and to the west are represented by the two dash-dotted lines on either side.

It may be of some importance to note that these trend lines run quite parallel to the outline of the combined Zones G-1 and G-2, shown in Figure 23. It must be emphasized, however, that the outline of Zones G-1 and G-2 and the above mentioned results from Figure 24 can only indicate a very general trend of the underlying formations in the absence of a more complete geologic survey of the relatively small area.

Figure 25 summarizes the results obtained from a similar treatment of dug wells in the same area. Since these data are more scattered and less applicable to generalizations, a more complete analysis could not be obtained without additional data.

Equilibrium Data for Radon-222 to Radium-226

Summarized in the table below are average concentrations of radium and radon for all drilled and all dug wells for which radium analyses were obtained.

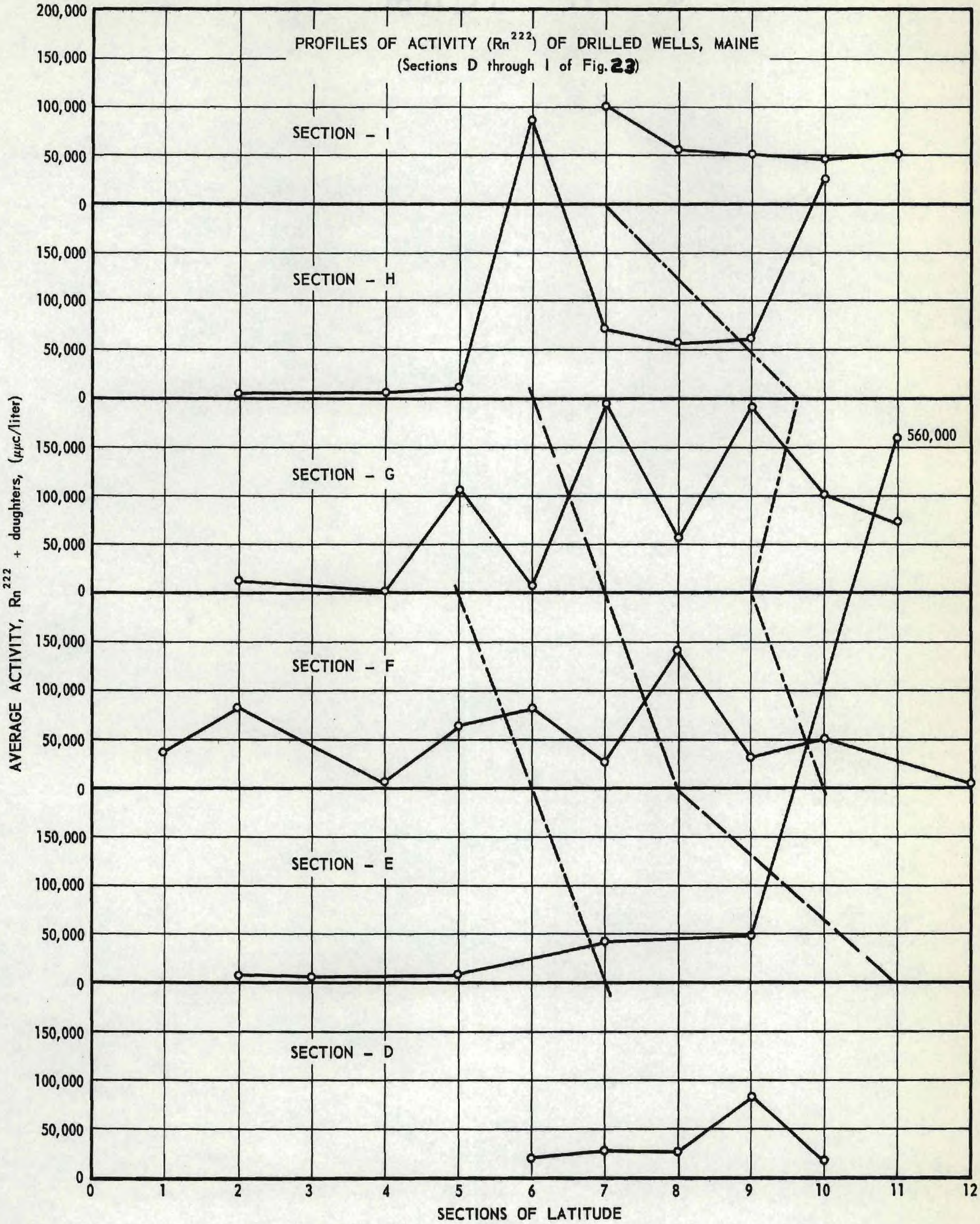


Fig. 24. Profiles of Activity (Rn^{222}) of Drilled Wells, Maine

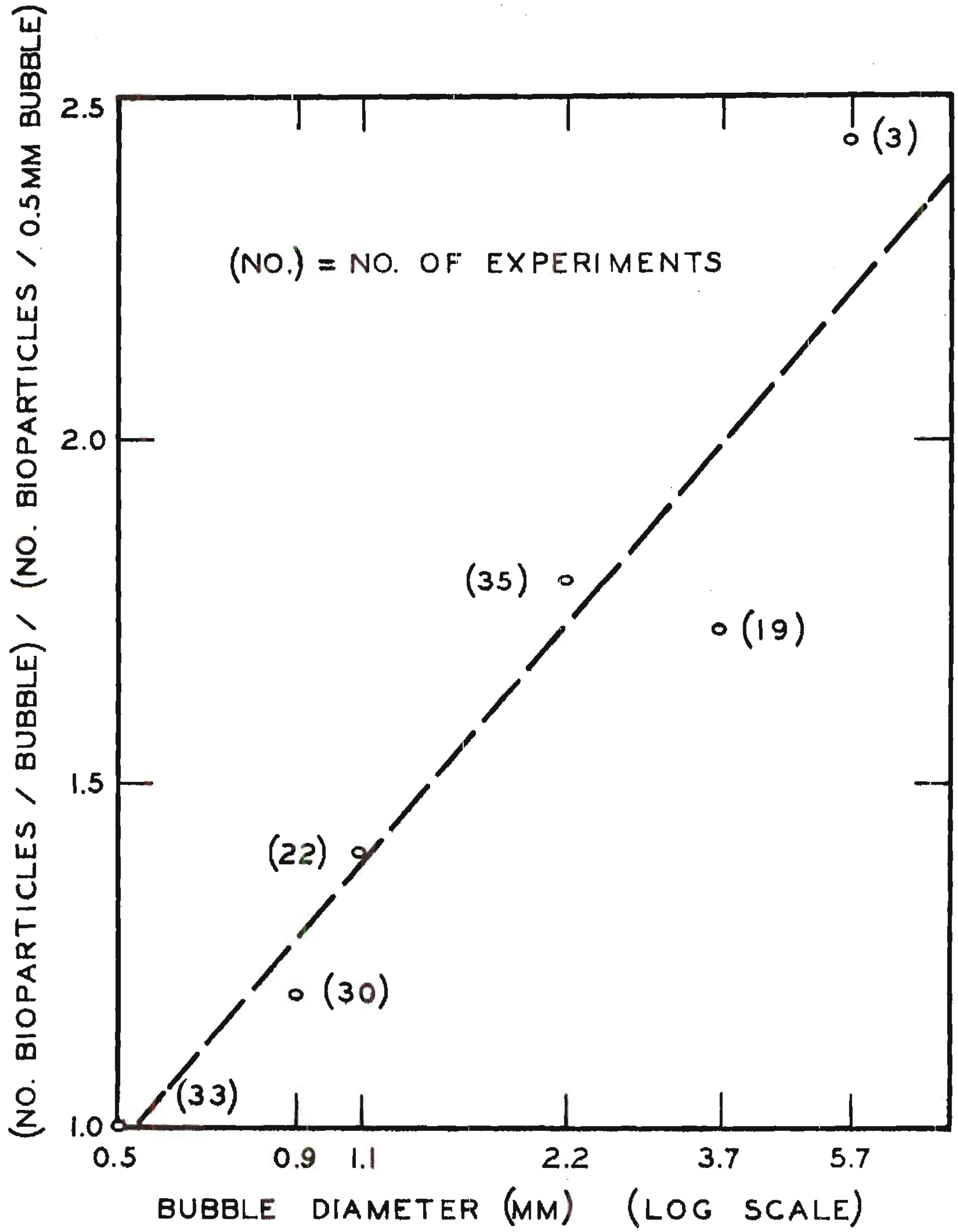


Figure 20. Ratio of Bioparticle Production Rate to Production Rate for 0.5 mm Bubbles versus Bubble Diameter

Table 11. Concentrations of Radon-222 versus Radium-226

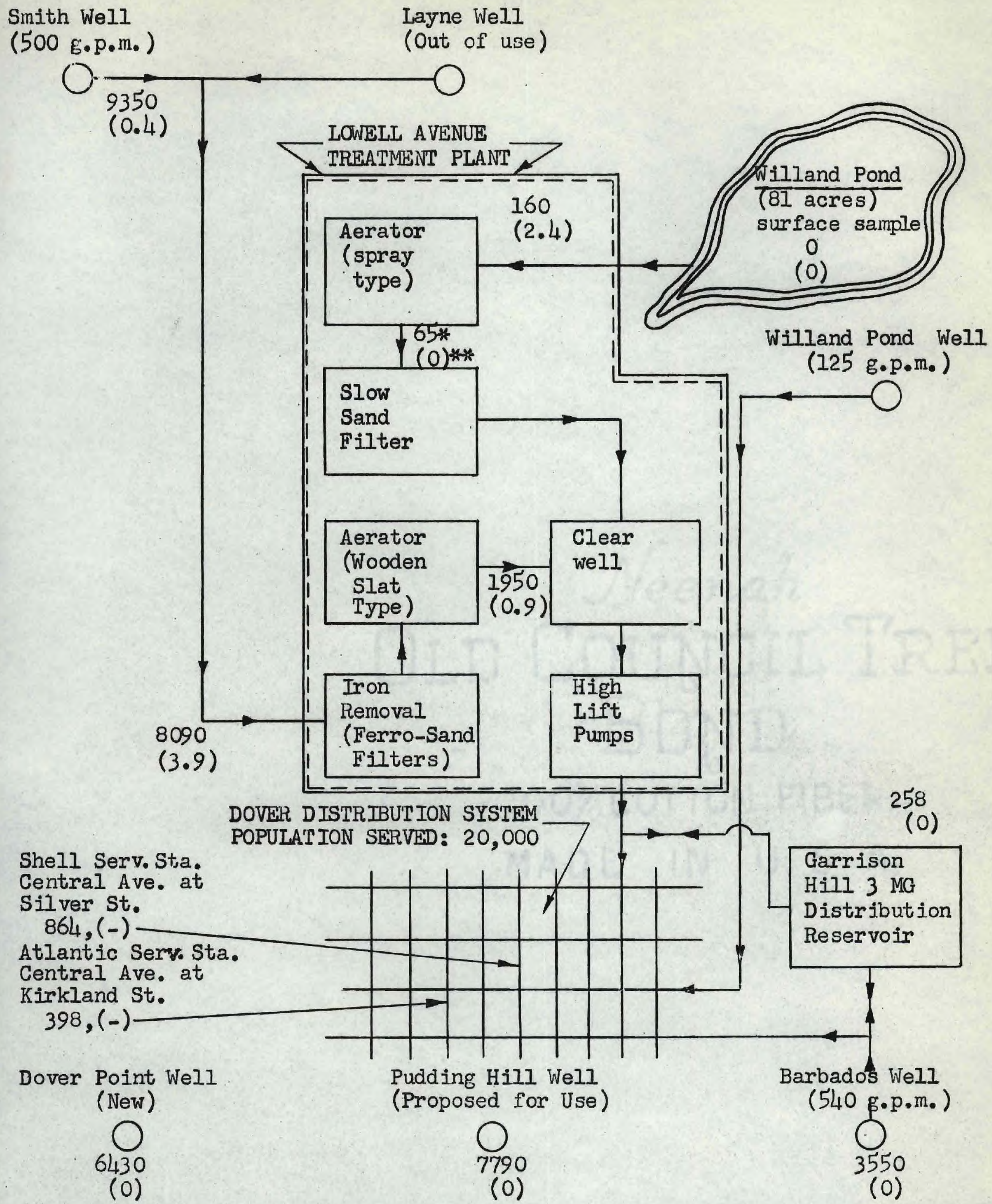
State	Type of Well	Number of Wells	Ave. Rn-222 ($\mu\mu c/\ell$)	Ave. Ra-226 ($\mu\mu c/\ell$)	Ratio Rn/Ra
Maine	Drilled	33	17,100	66	259
Maine	Dug	19	14,700	73	201
New Hampshire	Drilled	12	32,100	6.9	4,650
New Hampshire	Dug	3	5,990	4.1	1,460

This summary shows that the Radon-222 activity was found to be greatly in excess of its Radium-226 equilibrium value. The values of the radon-radium ratio for Maine may be low because of the inclusion of a few unusually high radium activities (See Appendix B).

Radon-222 and Radium-226 in the Dover, New Hampshire, Water Supply System

At the request of the Commissioner of Health for New Hampshire and the Mayor of Dover, water samples were collected from the Dover water supply system and analyzed for Radon-222 and Radium-226 on August 27, 1959.

Samples were collected from five of Dover's six ground water supplies and from Willand Pond, the only surface water supply. A diagram of the entire water supply system is presented in Figure 26. Since Layne Well was not in use, it could not be sampled. The bubbler containing the sample collected from the Willand Pond Well opened during transit, therefore, the sample volume could not be obtained.



Notes: * Upper figures denote activity of Rn-222 + daughters through Po-214 ($\mu\mu c/l$).
** Lower figures, in parenthesis, denote activity of Ra-226 ($\mu\mu c/l$).

Fig. 26. Flow Diagram of Water Supply System of Dover, New Hampshire

The exact radon concentration could not be determined.

Results of the analyses from 21 samples are of particular interest. Smith well water was found to contain a radon activity of 9350 compared to a maximum allowable concentration in water of 2000 $\mu\mu c/\ell$ (33). Similar concentrations were observed for the Dover Point, Pudding Hill and Barbados Wells. They were 6430, 7790, and 3550 $\mu\mu c/\ell$, respectively.

The Smith Well supply entered ferro-sand filter treatment with a radon activity of 8090 $\mu\mu c/\ell$ and left the aerator with an activity of only 1950 $\mu\mu c/\ell$. These results indicate that the treatment reduces the radon content of the water by 77 per cent. Similarly, the aerators for the surface supply from Willand Pond effect a reduction in radon activity of 68 per cent. A more complete evaluation of aeration and other treatment methods to remove radon from water is reported in the next section.

The three M.G. Garrison Hill distribution reservior for the water system was found to contain a concentration of radon of only 258 $\mu\mu c/\ell$. Therefore, it would appear that no radon hazard exists from this reservoir which contains water from several supply sources.

Two water samples taken near the center of the Dover distribution system, exhibited activities of only 864 and 398 $\mu\mu c/\ell$, less than the maximum allowable concentration value for radon (33).

The maximum concentration of Radium-226 found in the Dover water supply during the sampling program on August 27, 1959, was 3.9 $\mu\mu c/\ell$.

This value of activity before treatment is only about one-tenth of the maximum allowable concentration in water of 40 $\mu\mu c/\ell$ according to the National Committee on Radiation Protection (33).

It would appear that the Dover, New Hampshire, population is served with water which contains practically no Radium-226 in the distributed supply and that the concentration of Radon-222, although almost as much as four times the maximum allowable concentration at some wells, is reduced to well within the allowable concentration by conventional water treatment practices.

Radon Removal Studies

During the course of the sampling program, the need for a relatively inexpensive method for removing radon from private water supplies became apparent. In an effort to determine a good removal technique, several field tests were conducted. Items and procedures now in use in many homes, as well as equipment used in water treatment plants, were subjected to tests.

Since radon is a gas, it may be removed from water by aeration or by elevation of the temperature. The first technique, that of aeration, is that employed in the determination of radon as described in Chapter III and used in this sampling program. In an attempt to adapt these removal methods for use in private homes, three common household devices and procedures were investigated, a faucet aerator*, a faucet spray**, and boiling the water.

Tests were performed at sampling point No. 39 and yielded results as shown in Table 12. With a flow of 1.85 g.p.m. through the faucet aerator, 48 and 56 per cent of the dissolved radon was removed from the water. With the same flow through the spray nozzle, removal efficiencies of 17 and 18 per cent were obtained. Removal was not complete with either aeration device, even though the air entrapped was allowed to escape from the treated water by collecting the water in a 500 ml capacity beaker held six inches from the end of the faucet. In both cases, the amount of aeration induced depended upon the rate of flow of the water through the device. The greater radon removal efficiency obtained with the faucet aerator was due to the formation of tiny bubbles of air which thoroughly mixed with the water. This provided a very large air-water interface for the escape of radon from the water. The spray nozzle, however, dispersed the water in many tiny streams but provided very little actual mixing of air with the water.

As shown in Table 12, the boiling tests yielded removal efficiencies of 95 per cent for a one-minute boiling period and 100 per cent for a five-minute period based on triplicate results. In conducting the test, one liter of water was placed in a vessel six-inches in diameter. After one minute of boiling, triplicate samples were collected from the vessel. Another triplicate set was collected after a five minute boiling period.

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*Faucet aerator for use in private homes: "Bubble Stream", Mfg. by the Goodrie Company, U.S. Patent 2510395 and Patent Pending.

**Spray nozzle for use in private homes: "Faucet Queen" by the Faucet Queens, Inc., Chicago, Illinois, U.S.A., Patented.

Table 12. Results of Tests on Removal of Radon from Water

Method of Removal	Run Number	Number of Samples*	Activity Remaining (%)	Activity Removed (%)
Faucet Aerator	I	2	52	48
Faucet Aerator	II	3	44	56
Faucet Spray	I	2	83	17
Faucet Spray	II	3	82	18
Boiling (1 min.)	II	3	5	95
Boiling (5 min.)	II	3	0	100
Wooden Slat Aerator	D-1	3	23	77
Spray Aerator	D-2	2	32	68

*Activity remaining and activity removed are based on control samples with no treatment. Triplicate controls were analyzed for runs II and for D-1. Duplicate controls were analyzed for runs I and for D-2.

Two prototype water treatment plant aerators were examined for their effect on radon removal from water. The aerators were located at the Lowell Avenue Municipal Water Treatment Plant at Dover, New Hampshire. One aerator, of wooden-slat type construction for the removal of CO_2, was in operation in series with three ferro-sand filters for the removal of iron from water. Triplicate samples were collected both prior to ferro-sand filtration and after aeration. A radon removal efficiency of 77 per cent was observed with a flow of 500 g.p.m.. Another aerator, a wooden trough-type device, effected a 68 per cent removal efficiency as determined from a set of triplicate samples.

Even though excellent removal efficiencies were observed with some of the devices, two important problems concerning human exposure still remain. One problem exists because, even if 100 per cent removal of radon from water were achieved, only about one-fifth of the total alpha plus beta activity of Radon-222 plus daughters is removed. The other four-fifths of the activity comes from the non-gaseous daughter products of radon. The effective half-life of these daughter products is, however, only about 36 minutes. Therefore, essentially all the major activity will decay within a period of about six hours.

The other problem is that, unless provision is made for the dissipation of the removed radon to the outside, exposure to air-born radioactivity may pose a hazard. The various removal methods mentioned above merely move the radon from water to the surrounding air which may then be inhaled.

Further studies on the removal of radon from water should be expanded to include the removal of daughter products from the water, as well as studies on the ventilation of radon to the outside.

Variation of Activity with Duration of Pumping

From a review of the experimental data and the correlations of activity with well depth, it is obvious that information about another variable, time or rate of ground water extraction, would be of great value to properly interpret exposure concentrations. To observe the effect which length of pumping has upon the radon activity, a pumping test was performed at Sampling point No. 143 at Paris Hill, Maine.

The results of this study are presented in Figure 27. The initial radon activity was found to be less than one-half of the five-hour activity. The 15 minute activity was found to be approximately 125 per cent of the final activity. The activity over the final hours of the test is observed to vary linearly with time between an average radon activity of 70,700 $\mu\mu c/\ell$ at one hour to an average activity of 67,900 $\mu\mu c/\ell$ at five hours after time zero. This investigation indicates an apparent variation of activity with time of pumping at sampling point No. 143.

Similar results were observed at the Dielectric Company, sampling point No. 22. Since the company does not operate from 12:00 noon on Saturday to 7:00 A.M. on Monday of each week, the well is not used on weekends except for washing purposes at four company-owned houses.

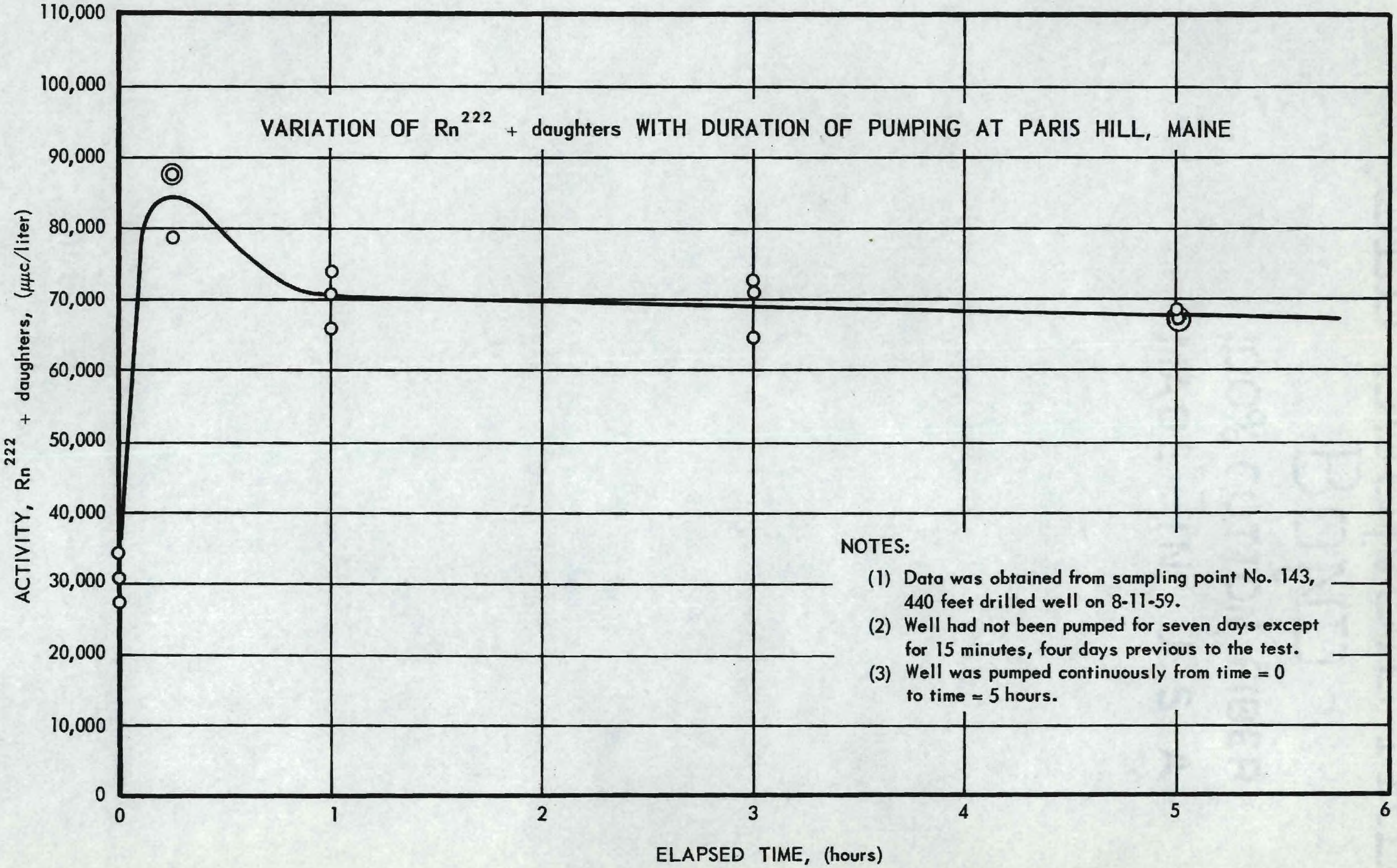

Fig. 27. Variation of Rn^{222} + Daughters With Duration of Pumping at Paris Hill, Maine

Samples were collected at noon Saturday and about 7:00 A.M. on Monday during two consecutive weekends. The results obtained are shown in Table 13 below.

Table 13. Radon activity at Dielectric Products Engr. Co., Inc., (No.22) Before and After Semi-idleness

Day and Date	Activity of Rn-222 + daughters ($\mu\mu c/\ell$)	Per cent Activity Monday with Respect to Previous Saturday (%)
Sat. 8/8/59	768,000	
Mon. 8/10/59	1,150,000	149
Sat. 8/15/59	864,000	
Mon. 8/17/59	1,120,000	139

As may be seen from the table, the activities of the well water is lower at the end of the work week than at the end of the one and one-half days of limited pumping. This variation would be expected from an interpertation of the results of the pump test conducted at Paris Hill.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions are drawn from this study:

(1) The experimental value of 3.798 days for the half-life of the gaseous radioactivity encountered in ground waters of Maine and New Hampshire shows that the gaseous radioactivity was Radon-222 which has a half-life of 3.825 days. This does not preclude the existence of other gaseous radioactive isotopes in these ground waters.

(2) It was found that 99.2 per cent of all the water samples from drilled wells in Maine contained concentrations of Radon-222 plus daughter products exceeding 2,000 $\mu\mu c/\ell$.

(3) Approximately 84 per cent of all the water samples from dug wells in Maine contained Radon-222 plus daughters concentrations exceeding 2,000 $\mu\mu c/\ell$.

(4) The radon activity distributions in Maine and New Hampshire were not found to be significantly different.

(5) The minimum, average, and maximum radon and radium activities obtained from all the wells and springs which were sampled in Maine are as follows:

	Radon-222 plus daughters through Polonium-214 ($\mu\mu c/\ell$)	Radium-226 ($\mu\mu c/\ell$)
Minimum	0	0
Average	53,700	65
Maximum	884,000	730
No. of Samples	228	55

(6) The minimum, average, and maximum radon and radium activities obtained from all wells and springs which were sampled in New Hampshire are as follows:

	Radon-222 plus daughters through Polonium-214 ($\mu\mu c/\ell$)	Radium-226 ($\mu\mu c/\ell$)
Minimum	2,510	0
Average	101,000	4.8
Maximum	1,130,000	23
No. of Samples	26	21

(7) For large areas, depth of well was not found to significantly influence the radon activity of well waters; however, when the area used as a basis for comparison was reduced in size to only a few square miles, radon activity was found to vary linearly with depth.

(8) In New Hampshire, a significant correlation was found to exist between depth of well and activity both within and without the Fitchburg Pluton. However, within the Pluton, activity decreased with increased depth, whereas without the Pluton, activity increased with depth.

(9) In New Hampshire, the Radium-226 activity decreased with increased depth, whereas in Maine, a trend could not be established.

(10) At the 90 per cent condifence limit, the average radon activities of drilled and dug wells in several geographic and geologic areas and zones were found to be statistically different.

(11) In Maine, drilled wells were found to contain significantly greater concentrations of radon than dug wells.

(12) Among all the geologic formations within the area sampled in Maine, the Waterville Formation, Zone G-1, was found to contain the highest concentrations of radon activity in drilled wells.

(13) A statistically significant difference between the average activities of drilled wells within and without the Fitchburg Pluton in New Hampshire was found.

(14) There appears to be a continuing high level of radon activity associated with the drilled wells within a relatively narrow band of geologic formations following the general outline of the Fitchburg Pluton in New Hampshire and the Waterville Formation in Maine as indicated by the highly significant difference obtained between the activities within and those without this narrow band.

(15) Limited studies on the variation of radon activity with duration of pumping showed that radon activity varied with the duration of pumping and the idle period between pumping. The activity from one well after about fifteen minutes of pumping was 125 per cent of the activity after five hours of pumping. Similar results were obtained from observations on other wells.

(16) In both Maine and New Hampshire, Radon-222 was found to be in excess of equilibrium with the Radium-226 present in the ground waters. The ratios of radon to radium in drilled wells in Maine and New Hampshire were found to be 259 and 4,650 respectively.

(17) From a limited study on the removal of radon from water, removal efficiencies were as follows: (1) 48 to 56 per cent with a faucet aerator, (2) 17 to 18 per cent with a faucet spray, (3) 95 to 100 per cent by boiling, and (4) 68 to 77 per cent with water treatment plant areators.

Recommendations

The following are recommendations for additional studies:

(1) The need for additional data from the areas considered in the study became apparent in order to give more significance to observations of certain trends of activity.

(2) A larger area needs to be studied in order to determine whether or not the areas considered were representative or merely areas

of abnormally high activity and whether or not the narrow band of high activity extends further to the north and/or to the south.

(3) To more intelligently define the effects of geology on the concentrations of radioactivity in ground waters, further studies need to be conducted on the variation of activity in the water with temperature, rainfall, depth of the water, and the rate of removal of the water from the ground.

(4) Further studies on the removal of radon from water should be expanded to include other methods of removal, the removal of daughter products, and the disposal of the removed radioactivity.

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APPENDIX A

TYPICAL FIELD DATA SHEET
TYPICAL LABORATORY DATA SHEET - RADON AND RADIUM IN WATER

Sampling Date: 8/20/59

FIELD DATA SHEET

1) Sample Designation	245
2) Location of Sampling Point	Cole's General Store East Sumner, Maine
3) Depth of Well	135 Feet
4) Type of Well	Drilled
5) Use of Well	Domestic
6) Date Well First Used	1953
7) Number of Persons Using Well	4
8) Ages of Persons Using Well	45, 54, 54, 80
9) Location of Well at Sampling Point	?
10) Collection Point within Water System	Sink in Store
De-emanation Method	
11) Bubbler Number	48
12) Time of Sample Collection	1:13 PM
13) Time of Radon Separation	1:15 PM
Dithizone Method	
14) Collection Bottle Number	———
15) Time of Sample Collection	———
16) Time of Radon Daughter Separation	———
Remarks	

Sampling Date: 8/20/59

LABORATORY DATA SHEET - RADON AND RADIUM IN WATER

	RADON	RADIUM
1) Sample designation	245	245
2) Bubbler number	48	48
3) Time & date of storage		2:15 AM 8/21
4) Time & date of Rn separation	1:15 PM8/20	2:54 PM 8/28
5) Time for Rn buildup from Ra (days)		7.53
6) Time & date of beginning of count	10:25PM8/20	1:07 PM 8/29
7) Time for Rn + daughter decay (min)	550	1333
8) Total alpha counts	1546	213
9) Duration of count (min)	20.00	30.00
10) C. P. M. (#8/#9)	77.3	7.10
11) Background (cpm)	1.4	1.90
12) Duration of background count	5 min.	30 min.
13) C. P. M. (#10-#11)	75.9	5.20
14) Rn removal effic. (%/100)	0.897	0.897
15) C. P. M. (#13/#14)	84.6	5.80
16) Counting efficiency (%/100)	0.548	0.687
17) D. P. M. (#15/#16)	154	8.44
18) Count ratio from decay curve (%/100)	2.80	2.56
19) D. P. M. (#17/#18)	55.0	3.30
20) % Rn buildup from Ra (%/100)		0.745
21) D. P. M. of Ra (#19/#20)		4.43
22) Sample volume (ml)	24.1	24.1
23) D. P. M./ℓ (#19 or #21 x 1000/#22)	2280	184
24) μμc/ℓ (#23/2.22)	1030	82.9

APPENDIX B

COMPLETE TABULATION OF FIELD DATA
(MAINE AND NEW HAMPSHIRE)

Note: Sample number provided with * denotes analysis for Pb-210 in addition to Radon-222 and/or Radium-226.

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Well	Date Family Began to Use	Type of Well	Depth of Well (ft.)	Date of Sample Collection	Activity of Rn-222 ($\mu\mu c/\ell$)	$\alpha + \beta$ Activity of Rn-222 + Dhtrs. thru Po-214 ($\mu\mu c/\ell$)	Activity of Ra-226 ($\mu\mu c/\ell$)
1 *	L. H. Bradway Lumber Co.	WINDHAM	dkg	22	18 20 4 5	1957	drl	93	7/31/59	6,940	34,800	
2 *	Dumar Motel	RAYMOND	dom com	2		1955	drl	96	7/29/59	12,700	63,800	
3 *	Raymond Water Co.	RAYMOND	dom com	50			dug	30	8/19/59	4,480	22,500	77
4 *	B.A. Mann	RAYMOND	dom	2	73,78	1953	drl	115	7/30/59	27,900	140,000	
5 *	Vincent Clark	RAYMOND	dom	3	40,2 69	1939	dug	20	8/19/59	928	4,660	0
6 *	Dr. Robert MacAuslan	RAYMOND	dom	6	2mo,3,5 8,34,34	1959	drl	168	7/30/59	48,600	244,000	
7 *	Donald VanDusen	RAYMOND	dom	2	45,45		drl	107	7/30/59	8,020	40,300	
8 *	Dodge	RAYMOND	dom com	3	45,51 50	1952	drl	101	7/30/59	13,600	68,300	
9 *	Geo. Henry	RAYMOND	dom	8	6 20,4	1955	jet		7/29/59	7,300	36,700	
10 *	Arnold Knox	RAYMOND	dom com	3	57,60 27	1949	dug	28	8/19/59	824	4,140	0
11 *	Winant	RAYMOND	dom	6	55,44,5 18,15,12	1944	dug	35	8/19/59	5,810	29,200	0
12 *	Reginald Brown	RAYMOND	dom	3	89-53	1925	drl	80	7/29/59	28,900	145,000	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (µµc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (µµc/l)	Activity of Ra-226 (µµc/l)
13 *	T.Kinnelly	RAYMOND	com	4	40,40 23,15	1946	drl	200	7/29/59	15,000	75,400	
14 *	Pine Hollow Lodge	RAYMOND	com	4	75,48 15,12	1951	drl	185	7/29/59	15,600	78,300	
20 *	Portland Pipeline Co.	RAYMOND	ind				drl	363	7/31/59	2,900	14,600	
21 *	Bill Smith	RAYMOND	dom	2	50,50	1956	drl	500	7/31/59	27,600	139,000	
22a *	Dielectric Products Co.	RAYMOND	ind dom	125 9	dom: 58,57 65,47 36,6 10,67 63 ind: ?	1948	drl	594	7/31/59	162,000	814,000	
22b *	Dielectric Products Co.	RAYMOND	ind dom			1948	drl	594	7/18/59	206,000	1,040,000	
22c *	Dielectric Products Co.	RAYMOND	ind dom			1948	drl	594	7/18/59	229,000	1,150,000	
22d	Dielectric Products Co.	RAYMOND	ind dom			1948	drl	594	8/8/59	153,000	768,000	127
22e	Dielectric Products Co.	RAYMOND	ind dom			1948	drl	594	8/10/59	228,000	1,150,000	
22f	Dielectric Products Co.	RAYMOND	ind dom			1948	drl	594	8/15/59	172,000	864,000	
22g	Dielectric Products Co.	RAYMOND	ind dom			1948	drl	594	8/17/59	224,000	1,120,000	47
23 *	Chas. Harmon	RAYMOND	dom	2	50,50	1934	drl	(85?)	7/31/59	115,000	579,000	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Well	Date Family Began To Use	Type of Well	Depth of Well (ft.)	Date of Sample Collection	Activity of Rn-222 ($\mu\mu c/\ell$)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 ($\mu\mu c/\ell$)	Activity of Ra-226 ($\mu\mu c/\ell$)
25 *	H.H. Zeiner	RAYMOND		2	56,60	1950 1958	drl dug	400 12	8/19/59	5,500	27,600	0
28 *	David Plumer	RAYMOND	dom	3			dug	60	7/30/59	1,300	6,500	
29 *	E.R. Clough's Grocery	RAYMOND	dom				drl	125	7/22/59	37,500	188,000	
32 *	Harold Bishop	RAYMOND	dom	2		1955	drl	124	7/30/59	23,800	120,000	
33 *	Rev. Pitcock	RAYMOND	dom	2	58,39	1955	drl	96	7/30/59	104,000	522,000	
34 *	Chas. Small	RAYMOND	dom	5	76,71 26,14,5	1949	drl	70	7/30/59	2,320	11,600	
35	Raymond Town Hall	RAYMOND	pub	16	40,(15 5 yrs)		drl		8/7/59	7,300	36,600	40
36 *	J.O. Small	RAYMOND	dom	4	57,53 18,15	1934	drl	50	7/30/59	6,310	31,700	
39a*	C.D. Brown	RAYMOND	dom	3	45,40 16	1952	drl	149	7/29/59	39,200	197,000	
39b*	C.D. Brown	RAYMOND	dom				drl	149	7/30/59	42,000	211,000	
39c*	C.D. Brown	RAYMOND	dom				drl	149	8/3/59	31,100	156,000	
39d*	C.D. Brown	RAYMOND	dom				drl	149	8/4/59	41,800	210,000	15
39e*	C.D. Brown	RAYMOND	dom				drl	149	8/6/59	46,400	233,000	86

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
39f	C.D. Brown	RAYMOND	dom				drl	149	8/6/59	40,400	203,000	
39g	C.D. Brown	RAYMOND	dom				drl	149	8/10/59	41,300	208,000	
39h	C.D. Brown	RAYMOND	dom				drl	149	8/12/59	48,200	242,000	
39A	C.D. Brown	RAYMOND	dom				drl	149	8/13/59	44,700	225,000	0
39B	C.D. Brown	RAYMOND	dom				drl	149	8/13/59	45,900	230,000	0
39C	C.D. Brown	RAYMOND	dom				drl	149	8/13/59	46,800	235,000	0
39i	C.D. Brown	RAYMOND	dom				drl	149	8/21/59	51,400	258,000	
39j	C.D. Brown	RAYMOND	dom				drl	149	8/21/59	46,800	235,000	
39k	C.D. Brown	RAYMOND	dom				drl	149	8/21/59	43,800	220,000	
39l	C.D. Brown	RAYMOND	dom				drl	149	8/21/59	42,100	211,000	
43	Wm. Covens	RAYMOND	dom				dug	12	7/20/59	2,020	10,200	
44	Lorenzo Messier	TOPSHAM	dom				dug	16	7/21/59	1,630	8,180	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
45	WGAN TV	RAYMOND	ind				dug		7/20/59	3,850	19,300	
46	Winnabell Walton	RAYMOND	dom				dug		7/20/59	4,360	21,900	
47	Fisher Quarry	TOPSHAM					sprg		7/21/59	22,400	112,000	
48	The Shanty Store	RAYMOND	dom				drl	60	7/20/59	554	2,780	
49	Fisher Quarry	TOPSHAM					pool		7/21/59	93.7	470	
50	F.W. Hopkins	RAYMOND	dom				drl	85	7/22/59	2,830	14,200	
51*		RAYMOND	dom	3	5,22 29	1937	dug		7/30/59	995	4,990	
52	A.W. Strout	RAYMOND	dom				dug	16	7/22/59	712	3,570	
53	Augusta Plummer	RAYMOND	dom				dug	24	7/22/59	761	3,820	
54	Z.H. Strout	RAYMOND	dom				dug	22	7/22/59	5,410	27,200	
55	Kenneth Newcomb	RAYMOND	dom				drl		7/22/59	12,700	63,800	
56	John J. Conners	CASCO	dom				drl	68	7/23/59	4,950	24,900	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (µµc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (µµc/l)	Activity of Ra-226 (µµc/l)
57	Phillips Edwards	CASCO	dom				dug	12	7/23/59	1,470	7,390	
58	R.H. Hamor	NAPLES	com				drl	148	7/23/59	3,000	15,100	
59	Burnham Bros. Inc.	NAPLES	dom dkg				drl	127	7/23/59	16,000	80,400	
60	W.F. Donahue	NAPLES	com				sprg		7/23/59	559	2,810	
61	Bridgeton Pines	NAPLES	dom				drl	200+	7/23/59	5,450	27,400	
62	Edward Stanton	STANDISH	dom				dug	30	7/23/59	1,090	5,480	
63	Howard Dyer	STANDISH	dom				drl	60	7/23/59	15,000	75,400	
64	Andrew Glantz	WINDHAM	dom				dug	16	7/23/59	1,060	5,330	
65	WGAN TV	RAYMOND	ind				drl	175	8/10/59	7,200	36,100	0
66 (#)	WGAN TV	RAYMOND	ind				drl	150	7/23/59	26.7	134	
67 (#)	WGAN TV	RAYMOND	ind				drl	150	7/23/59	22.1	111	
67A	WGAN TV	RAYMOND	—				air		7/23/59	4.7	23.6	

(#) From Sampling Point No. 65 as well was being drilled.

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
68	F.E. Allen	GRAY	dom				drl	113	7/24/59	45,900	230,000	
69	Gerald Kimball	GRAY	dom				drl	106	7/24/59	19,700	98,900	
70	R.W. Sawyer	GRAY	dom				dug	25	7/24/59	246	1,240	
71	F.H. Emery	NEW GLOUCESTER	dom				dug		7/24/59	6,310	31,700	
72	H.B. Gardner	NEW GLOUCESTER	dom				drl	200	7/24/59	16,700	83,900	
73	Geo. Hahn	NEW GLOUCESTER	dom				drl	45	7/24/59	4,730	23,700	
74	J.E. Norton	GRAY	dom				dug	15	7/24/59	599	3,010	
75		RAYMOND	dom				sprg		7/24/59	5,770	29,000	
76	Gerald Wing	RAYMOND	dom				dug	12	7/24/59	667	3,350	
77	Harry Lewis	GRAY	dom				dug	16	7/24/59	1,580	7,930	
78	Lake Valley Restaurant	NEW GLOUCESTER	com				dug	23	7/24/59	1,220	6,120	
79	H.T. Merrill	GLOUCESTER	dom				dug	50	7/24/59	581	2,200	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
80	Robt. Whitman	GRAY	dom				drl	45	7/25/59	45,500	228,000	
81	Raymond Whiten	GRAY	dom				dug	20	7/25/59	2,320	11,600	
82	Edgar Foster	GRAY	dom				dug		7/25/59	3,610	18,100	
83	Martha Robinson	RAYMOND	dom				sprg		7/25/59	4,320	21,700	
84	Sidney A. Flanagan	CASCO	dom				dug	14	7/25/59	4,410	22,200	
85	Arthur White	CASCO	dom				drl	120	7/25/59	14,800	74,300	
86	Bean	CASCO	dom				drl	100	7/28/59	4,770	24,000	
87	Bill Max-Field	CASCO	dom				drl	90	7/28/59	9,280	46,600	
88	A.G. Norton	NAPLES	dom				drl	60	7/28/59	10,500	52,800	
89	Wyman Pierce	CASCO	dom				drl	75	7/28/59	5,270	26,500	
90	E.J. Berry	CASCO	dom				dug	12	7/28/59	1,600	8,040	
91	L.A. Meseire	CASCO	dom				sprg		7/28/59	6,260	31,500	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (µµc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-226 (µµc/l)	Activity of Ra-226 (µµc/l)
92	C.G. Shaw	STANDISH	dom				dug	14	7/28/59	268	1,350	
93	J.F. Ames	STANDISH	dom				dug	10	7/28/59	2,140	10,800	
94	Sydney Smith	STANDISH	dom				dug	20	7/28/59	824	4,140	
95	Benjamin Bucci	STANDISH	dom				drl	100	7/28/59	1,420	7,140	
96	Edward Tibbetts	HOLLIS	dom				sprg		7/28/59	7,210	36,200	
97	Milton Smith	HOLLIS	dom				sprg		7/28/59	1,050	5,280	
98*	Dillingham	NAPLES	dom				dug		7/29/59	2,860	14,400	
99*	E.H. Lehman	NAPLES	dom				drl		7/29/59	3,200	16,100	
100*	C.E. Barnes	SEBAGO	dom				dug	22	7/29/59	4,320	21,700	
101*	H. Thombs	SEBAGO	dom				dug		7/29/59	1,300	6,530	
102*	Cedilnik	STANDISH	dom				drl	100	7/29/59	112,000	562,000	

<u>CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER</u> - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 ($\mu\mu c/l$)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 ($\mu\mu c/l$)	Acitvity of Ra-226 ($\mu\mu c/l$)
103*	M. Thorn	STANDISH	dom				dug	20	7/29/59	1,610	8,090	
104*	East Raymond Fire House	RAYMOND					drl		7/30/59	9,280	46,600	
105*	A.V. Blais	GRAY	dom	4	50;23, 20,11mo	1949	drl	125	7/31/59	9,050	45,400	
106*	John Shaw	CUMBERLAND	dom	2	75,38	1957	drl	240	7/31/59	19,200	96,500	
107*	Merrill Farm	CUMBERLAND	dom com	4	47;46 19,13	1951	drl		7/31/59	1,850	9,290	
108*	Raymond Mains	CUMBERLAND	dom	4	35;33 10,14	1959	drl	250	7/31/59	869	4,360	
109*	Newman Barter	NORTH YARMOUTH	dom	6	58;50 40,40 20;19	1956	drl	346	7/31/59	12,100	60,800	
110*	Caryl Baldwin	GRAY	dom	4	67;44 44,17	1941	drl	211	8/31/59	3,210	16,100	
111*	E.L. Morse	GRAY	dom	10	69;40 40;30 20;16 13,10 4,2mo	1918	drl		8/31/59	2,350	11,800	
112*	E.K. Babbidge	POWNAL	dom	3	47,47 13	1953	drl		8/3/59	3,260	16,400	
113*	B.A. Hall	DURHAM	dom	36	50;44 17,12 7,7,30>10	1944	drl	130	8/3/59	2,400	12,100	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
114*	Ernest Tebbets	DURHAM	dom	4	38,36 9,6	1957	drl	95	8/3/59	1,070	5,380	
115*	Clifford Dunham	FREEPORT	dom	6	67,39 37,12 7,2	1955	drl	91	8/3/59	12,600	63,300	
116*	C.W. Kift	FREEPORT	dom	6	41,37 26,21 15, 7	1958	drl	150	8/3/59	11,400	57,300	
117*	Wm. Trufand	DURHAM	dom	7	60,51 51,47 40,16 14		drl		8/3/59	487	2,450	
118*	Lawrence Silvius	DURHAM	dom	7	56,51 47,10 10,11 13	1952	drl	136	8/3/59	3,770	18,900	
119	Jackson Tupper	DURHAM	dom	5	38,33 14,12 19mo	1953	drl	350	8/3/59	698	3,510	
120*	Randall Hill	HARRISON	dom	2	83,63	1908	dug		8/4/59	1,770	8,890	270
121*	E.H. Chaplin	HARRISON	dom	4	31,29 5,1	1954	drl	47	8/4/59	4,680	23,500	32
122*	Wyman Dresset	HARRISON	dom	8	38,37 18,17 17,17 14,5mo	1921	dug		8/4/59	1,360	6,830	190
123*	J.C. Haggarty	HARRISON	dom	5	42,39 12,10 8	1954	drl	140	8/4/59	8,200	41,200	0

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
124*	Loren Brett	OTISFIELD	dom com	6	45;36 11;9 8,1	1937	drl	105	8/4/59	1,770	8,890	0
125*	Hazel Terril	POLAND	dom	2	50+	1939	drl	65	8/4/59	14,100	70,900	
126*	Howard Record	OXFORD	dom	6	50;42 15;11 8;6	1950	drl	90	8/4/59	37,500	188,000	180
127*	King's Store	OXFORD	dom	4	47;21 21,1	1956	drl	300	8/4/59	22,900	115,000	440
128*	Goddard	POLAND	dom	3	53,34 13	1957	drl	80	8/4/59	8,420	42,300	0
130*	Quito Shop	CASCO	com			1951	drl	60	8/4/59	50,900	256,000	2.3
131*	Glen Craft	OTISFIELD	dom com				drl	70	8/4/59	6,350	31,900	160
132*		OTISFIELD					drl	138	8/4/59	8,870	44,500	0
133*	Harold Tucker	POLAND	dom	2	52,57	1943	drl	45	8/5/59	1,560	7,840	400
134*	Ralph Holt	MECHANIC FALLS	dom	14	2 to 64	1957	drl	63	8/5/59	11,900	59,800	0
135*	A.R. Locke	OXFORD	dom com	2	51,41		drl	96	8/5/59	57,700	290,000	98
136*	A.J. Ham	MECHANIC FALLS	dom	2	75,75	1944	drl	107	8/5/59	29,000	146,000	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
137 *	Harold Morrell	POLAND	dom	3	46,44 72	1950	drl	268	8/5/59	5,320	26,700	130.
138 *	Ernest Leonard	POLAND	dom	4	50,60 80,53	1958	drl	130	8/5/59	27,500	138,000	0.8
139	Well no. 3 South Paris Water Works	PARIS	pub				gravel packed	55	8/7/59	1,890	9,500	
140	Well no. 2 South Paris Water Works	PARIS	pub				gravel packed	48	8/7/59	1,370	6,880	
141	Well no. 1 South Paris Water Works	PARIS	pub				gravel packed	55	8/7/59	0	0	
142	South Paris Water Works Garage	PARIS	pub				gravel packed		8/7/59	649	3,260	110
143 (#)	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/7/59	9,370	47,000	
143A	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	6,800	34,200	

(#) Sample partly destroyed - activity recorded is an indication of true activity only.

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (µµc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (µµc/l)	Activity of Ra-226 (µµc/l)
143B	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	6,080	30,500	
143C	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	5,500	27,600	
143D	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	17,500	87,900	
143E	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	15,700	78,800	
143F	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	17,500	87,900	
143G	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	14,800	74,400	
143H	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	14,200	71,300	
143I	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	13,200	66,300	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use Of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
143J	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	12,900	64,800	
143K	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	14,200	71,400	
143L	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	14,500	72,800	
143M	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	13,600	68,300	
143N	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	13,500	67,800	
143O	Well no. 1 Paris Hill Water Works	PARIS	pub				drl	444	8/11/59	13,500	67,800	
144	Well no. 2 Paris Hill Water Works	PARIS	pub			1957	drl	440	8/7/59	30,600	154,000	
145	Well no. 3 Paris Hill Water Works	PARIS	pub				drl	500	8/7/59	38,100	191,000	
146*	Geo. Colby	PARIS	dom				W WKS		8/7/59	4,250	21,400	0

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use Of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
147 *	West Paris Water Works	PARIS	pub				Gravel Packed	44	8/7/59	2,120	10,600	96
149 *	James G. Chadbourne	BRIDGTON	dom			1924	dug	35	8/7/59	1,030	4,750	4.9
150 *	B.F.Frisbee	BRIDGTON	dom	2	77,57	1909	sprg		8/7/59	968	4,860	
151 *	Edward Bean	WATERFORD	dom	3	51,51 25	1956	drl	116	8/7/59	6,400	32,200	0
152 *	Osmane Towne	NORWAY	dom	5	48,42 16,11 5	1951	dug	10	8/7/59	964	4,840	
153 *	Herbert Gregg	WATERFORD	dom	3	49,44 4	1954	drl	175	8/7/59	4,500	22,600	0
154 *	Oscar Twitchell	OXFORD	dom	4	46,35 16,11	1959	drl	260	8/7/59	32,200	162,000	13
155 *	Henry Woodworth	PARIS	dom	4	59,58 11,9	1910	dug	10	8/7/59	1,690	8,480	0
156	Carl Wilson	HEBRON	dom	3	67,53 6	1953	drl	118	8/7/59	1,010	5,080	25
157	Cookie Parsons	PARIS	dom	3	24,24 4	1959	drl	260	8/7/59	1,440	7,240	340
158	Frances Bushey	NORWAY	dom	3	67,61 57	1956	drl	273	8/7/59	1,340	6,730	0.8

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
159	Jordan Bay Lake Sebago	RAYMOND					Lake		8/9/59	11.2	56.2	.41
160	Howard Bamford	POLAND	dom	5	32,31 7,4,3	1958	drl	147	8/10/59	5,270	26,500	
161	Wilfred Mixer	MINOT	dom	3	37,37 5	1955	drl	189	8/10/59	43,600	219,000	
162	Richard Nelson	MINOT	dom	5	38,34 11,10 6	1958	drl	130	8/10/59	550	2,760	
163	Thomas Slattery	MINOT	dom	7	76,65 48,42 21,18 17	1959	drl	152	8/10/59	171,000	859,000	
164	Ina Millett	HEBRON	dom com	3	73,58 49	1955	drl	233	8/10/59	1,230	6,180	
165	Roneldo Lapoinpe	AUBURN	dom	2	59,48	1952	dug	15	8/10/59	413	2,080	
166	Donald Windle	AUBURN	dom	3	47,42 22	1953	drl		8/10/59	17,700	88,900	
167	J.C. Bishop	AUBURN	dom	2	43,40	1957	drl	94	8/10/59	11,700	58,800	
168	Phillip Hitt	AUBURN	dom	3	54,51 28	1949	drl	132	8/10/59	6,710	33,700	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use Of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	α+β Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
169	David Reid	TURNER	dom	2	71,65	1919	dug	20	8/10/59	223	1,120	
170	Carleton Cox	NORWAY	dom	12	74,70,35 37,27,25 17,15,13 11,7,5	1949	drl	222	8/11/59	991	4,970	
171	Frank Gibson	WATERFORD	dom	11	70,69,31 19,18,31 7,6,3,2, 10days	1949	drl	300	8/11/59	12,100	60,800	
172	Bernard Morgan	GREENWOOD	dom	9	81,54,50 48,40,39 15,11,5	1959	drl	207	8/11/59	1,910	9,590	
173	Mary Parham	WOODSTOCK	dom	4	77,65,50 50	1949	dug		8/11/59	1,330	6,680	
174	A.R. Henderickson	WOODSTOCK	dom	10	62,60,38 36,25,20 15,11,8,4	1955	drl	174	8/11/59	491	2,460	
175	North Paris Co.	PARIS	dom	1	60	1939	drl	132	8/11/59	941	4,720	
176	Howard Gurney	PARIS	dom	6	39,34,13 9, 7, 6	1950	drl	137	8/11/59	2,260	11,300	
177	Ronald Woodworth	PARIS	dom	5	31,25,18 6,10mo	1957	drl	84	8/11/59	13,000	65,300	
178 *	Herbert Mason	GREENWOOD	dom	2	65,65	1909	dug	23	8/12/59	1,940	9,740	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
179*	Newtons Store	BETHEL	dom	8	65,55,55 64,29,19 18,10		dug		8/12/59	658	3,310	
180*	Truman Thursoan	RUMFORD	dom	5	44,37,13 12,8	1915	sprg		8/12/59	296	1,490	
181*	Marshall McMillan	RUMFORD	dom	2	67,47	1937	sprg		8/12/59	1,120	5,630	
182*	D.H. Robbins	WOODSTOCK	dom	2	72,64	1939	sprg		8/12/59	0	0	
183*	Jaiius Billings	MILTON	dom	7	73,42,36 14,12,9 8	1959	dug		8/12/59	802	4,030	
184*	Charles Poland	MILTON	dom	3	80,59,55	1925	dug	23	8/12/59	2,570	12,900	
185*	B.N. Werner	WOODSTOCK	dom			1955	drl	176	8/12/59	941	4,720	
186*	Ernest Lungan	PARIS	dom	4	32,30,10 9	1954	drl	85	8/12/59	1,930	9,690	
187*	Charles Cooper	BUCKFIELD	dom com	10	63,61,35 35,9,7,5 5,5,1	1947-1954	3 wells dug	24 8 10	8/12/59	377	1,890	
188*	W. Jorgensen	BUCKFIELD	dom	3	64,56,25	1954	drl	93	8/12/59	3,310	16,600	

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	α+β Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
189*	Earle Colby	BUCKFIELD	dom	8	40,39,27 27,8,2,3 8mo	1959	drl	92	8/12/59	2,280	11,400	
190*	March Noris	BUCKFIELD	dom	3	49,44,12	1956	dug		8/12/59	899	4,520	
191*	F.H. Littlefield	RAYMOND	dom	3	44,44,15	1954	dug	11	8/12/59	1,870	9,390	
192	Pegmatite Outcropping	CASCO					Hwy drain		8/13/59	2,290	11,500	0
193	Gusta Jokian	WATERFORD	dom	1	60	1924	dug	25	8/13/59	115	578	
194	H.F. Durgin	WATERFORD	dom	2	60,60	1944	sprg		8/13/59	363	1,820	
195	Albert Kimball	ALBANY	dom	2families		1955	dug		8/13/59	100	502	
196	Gilbert Rich	ALBANY	dom	2	30,30	1929	sprg		8/13/59	91	457	
197	Charles Chapin	BETHEL					dug	15	8/13/59	26.2	132	0
198	Boblowes Store	GREENWOOD	dom	6	36,31,9 8,5,14mo	1951	dug	15	8/13/59	1,300	6,530	
199	Merton Warren	BRIDGTON	dom	6	28,27,9 5,3,1	1959	dug	12	8/14/59	2,450	12,300	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
200	G.C. Hilton	BRIDGTON	dom com	2	58,50	1949	drl	120	8/14/59	23,600	119,000	
201	J.K. Manchester	FRYEBURG	dom	2	74,74	1954	drl	85	8/14/59	2,090	10,500	
202	J.K. Manchester	FRYEBURG	dom	2	74,74	1917	dug	20	8/14/59	79.7	400	
203	Owen Currier	FRYEBURG	dom	2	37,34	1953	dug	20	8/14/59	901	4,520	
204	State of Maine Wayside Park	U.S. 302 FRYEBURG	pub				dug		8/14/59	4,770	23,900	
205	Stillman F. Barker	FRYEBURG	dom	2	74,72	1949	drl	126	8/14/59	20,900	105,000	
206	E.R. Walker	BROWNFIELD	dom	2	69,50	1947	dug	18	8/14/59	514	2,580	
207	E.B. Caswell	BROWNFIELD	dom com	3	49,44,12	1956	drl	180	8/14/59	23,400	117,000	
208	C.H. Dunn	BROWNFIELD	dom com	8	58,49,29 16,6,4,½ 29	1952	drl	212	8/14/59	4,640	23,300	
209	Charles Ford	DENMARK	dom	3	32,26,5	1950	drl		8/14/59	47,700	239,000	
210	Flora True	DENMARK	dom	2	89,81	1909	dug		8/14/59	1,540	7,730	
211	Bert Sawyer	DENMARK	dom	2	53,41	1953	drl	26	8/14/59	10,600	53,200	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 ($\mu\mu c/l$)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 ($\mu\mu c/l$)	Activity of Ra-226 ($\mu\mu c/l$)
212	Ada F. Merrill	BRIDGTON	dom	1	81	1889	dug	33	8/14/59	86.0	432.0	
213*	H.W. Farris	BRIDGTON	dom				dug	30	8/17/59	109	547	
214*	H.W. Farris	BRIDGTON	dom				drl	120	8/17/59	22,400	112,000	
215*	Ivan LaPointe	SEBAGO	dom	5	45,42 17,16 6	1948	drl	152	8/17/59	12,200	61,300	
216*	M.F. Brown	SEBAGO	dom	4	43,41 20,16	1952	drl	96	8/17/59	3,670	18,400	
217*	Edson H. Stacey	BALDWIN	dom	3	35,33 14	1949	dug	8	8/17/59	2,840	14,300	
218*	Charlie Gain	LIMINGTON	dom	3	68,65 31	1953	dug	15	8/17/59	1,190	5,980	
219*	Kenneth Edge- comb	LIMINGTON	dom com	12			sprg		8/17/59	964	4,840	
220	R.S. Haley	LIMINGTON	dom	6	41,41 15,12 9,6	1918	dug	12	8/17/59	1,170	5,880	
221	Austin W. Smith	HOLLIS	dom	2	76,68		sprg		8/17/59	4,450	22,300	
222*	Russell Coffin	NEW GLOUCESTER	dom	5	62,40 14,35,15	1953	sprg		8/17/59	8,290	41,600	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	α+β Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
223 *	J.D. Manahan	POWNAL	dom	5	80,79 58,47 15	1959	drl	310	8/17/59	11,300	56,700	
224 *	Edward Hanson	NORTH YARMOUTH	dom	8	63,58 32,31 12,7 4,18mo	1958	drl	186	8/17/59	847	4,250	
225 *	Lawrence Carter	POWNAL	dom	4	45,36 18,16	1953	drl	110	8/17/59	55,400	278,000	
226 *	Fan Polakewich	FREEPORT	dom	2	64,37	1950	drl	90	8/17/59	13,500	67,800	
227 *	Ori Packard	FREEPORT	dom	5	69,49 44,15 12	1950	drl	217	8/17/59	2,850	14,300	
228 *	Lorenzo Small	FREEPORT	dom	2	65,65	1950	dug	16	8/17/59	622	3,320	
229 *	Deep Cut Repeater Station	BRUNSWICK	dkg				drl		8/17/59	2,020	10,200	
230	Earl E. Silver, Sr.	FREEPORT	dom	9	47,40 35,33 13,12 11,19 17	1955	drl	170	8/17/59	1,070	5,370	

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	α+β Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
231 *	Carl C. Dudley	WOODSTOCK	dom	9	82,69,40 37,35,35 12,10,3	1951	drl	165	8/18/59	223	1,120	14
232 *	G.R. Alvisy	RUMFORD		8	73,43 4mo	1954	sprg		8/18/59	2,640	13,300	2.0
233 *	McKlusky	RUMFORD	dom	5	49,47,17 13,11	1958	drl		8/18/59	1,050	5,270	0
234 *	Emile Faucher	RUMFORD	dom	7	53,49,20 20,17,15 12	1955	sprg		8/18/59	671	3,370	0
235 *	Merle Philbrick	MEXICO	dom	18	63,62,25 22,35,35		dug		8/18/59	70.3	353	0
236 *	Joseph Maddix	MEXICO	dom	2	60,60	1950	drl	105	8/18/59	7,340	36,800	12
237 *	Alfred Richard	RUMFORD	dom	6	37,34,12 11,8,4	1959	dug	22	8/18/59	1,120	5,630	730
238 *	C.L. Weld	DIXFIELD	dom	2	71,75	1953	drl	140	8/18/59	721	3,620	0
239 *	Helen Leslie	DIXFIELD	dom	1	63	1943	drl	340	8/18/59	937	4,700	0
240 *	Phill Benner	CARTHAGE	dom	5	64,40,37 8,6	1946	dug		8/18/59	1,290	6,480	0
241 *	Victor Karvel	DIXFIELD	dom	4	44,42,11 5	1945	dug	40	8/18/59	716	3,590	0

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
242 *	Merlyn Morrill	SUMNER	dom	2	65,58	1945	drl		8/20/59	482	2,420	95
243 *	Leroy S. Risbee	SUMNER	dom	2		1949	dug	25	8/20/59	126	633	0
244 *	R.F. Gammon	HARTFORD	dom	3	58,52 11	1909	dug	28	8/20/59	0	0	52
245 *	Cole's Store	SUMNER	dom	4	80,54 54,45	1953	drl	135	8/20/59	1,030	5,180	83
246	W.E. Davis	RUMFORD	dom	11	37,36 35,34 13,11 8,8,6 5,1	1930	drl	165	8/20/59	16,400	82,400	3.[illegible]
247	Ralph Kidder	PERU	pub	60		1951	drl	350	8/20/59	4,380	22,000	1.0
248	Benjamin Roberts	PERU	dom	5	82,46 43,28 14		dug	17	8/20/59	3,650	18,300	2.8
249	Stanley Jonaitis	PERU	dom	4	70,67 36,32	1939	dug	18	8/20/59	168	844	
250	Hazelton Store	PERU	com	5	70,35 34,12	1937	dug	9	8/20/59	1,880	9,450	0
251	F.A. Jacques	HARTFORD	dom	2	62,52	1949	dug	30	8/20/59	572	2,870	67

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (MAINE & NEW HAMPSHIRE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
252	Albah Hendrixson	HARTFORD	dom	2	73,69	1948	dug	16	8/20/59	545	2,740	0
D-1 *	Layne & Smith Well Filter Plant & Pumping Station (raw water)	DOVER, N.H.							8/27/59	1,490	7,480	0.8
D-2									8/27/59	1,670	8,390	11.
D-3									8/27/59	1,670	8,390	0
D-4 *	Same as above except after ion exchange and aeration	DOVER, N.H.							8/27/59	403	2,020	0
D-5									8/27/59	413	2,080	0
D-6									8/27/59	346	1,740	2.8
D-Air	L&S Well Filter Plant & Pumping Station air Sample	DOVER, N.H.							8/27/59	3.5	17.6	
D-7 *	Dover Point Well	DOVER, N.H.						39	8/27/59	1,280	6,430	0
D-8 *	Barbadoes Well	DOVER, N.H.							8/27/59	707	3,550	0
D-10 *	Garrison Hill Dist. Reservoir	DOVER, N.H.							8/27/59	51.4	258	
D-11 *	Willard Pond	DOVER, N.H.							8/27/59	0	0	0
D-13 *	Smith Well	DOVER, N.H.							8/27/59	1,860	9,350	0.4

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (NEW HAMPSHIRE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	α+β Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
D-14 *	Willard Pond Water at Treat-	DOVER, N.H.							8/27/59	39.5	198	
D-15	ment Plant	(Pop. 20,000)							8/27/59	24.1	121	2.4
D-16 *	Willard Pond Water after aeration, before	DOVER, N.H.							8/27/59	16.2	81.4	
D-17	slow sand fil- tration								8/27/59	9.8	49.2	0
D-18 *	Pudding Hill	DOVER, N.H.							8/27/59	1,090	5,470	
D-19	Well								8/27/59	2,000	10,100	0
D-20 *	Shell Service Station, Central Ave. at Silver St.	DOVER, N.H.							8/27/59	172	864	
D-21 *	Atlantic Service Station, Central Ave. at Kirkland	DOVER, N.H.							8/27/59	79.3	398	
15 *	Henri H. Cote	W. NOTTINGHAM	dom	8	45,34 26,7 6,4,3 3mo.	1958	drl	80	8/26/59	35,800	180,000	9.1
18 *	Peter Jurgenson	NOTTINGHAM	dom	2	67,58	1957	drl	214	8/26/59	8,690	43,600	4.2
19 *	Stuart Hodgdon	W. NOTTINGHAM	dom	3	54,48 17	1957	drl		8/26/59	49,500	214,000	3.4

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (NEW HAMPSHIRE)

Sample Number		Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	$\alpha+\beta$ Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
55		R.H. Gustin	W.NOTTINGHAM	dom	3	64,39 20	1954	drl	25	8/26/59	48,600	244,000	23
$72\text{-}1_1$		P.E. Pendleton	DEERFIELD	dom	2	61,60	1953	drl		8/28/59	214,000	1,080,000	0.9
$72\text{-}1_2$		P.E. Pendleton	DEERFIELD	dom	2	61,60	1953	drl		8/28/59	237,000	1,190,000	37
$72\text{-}A_1$		P.E. Pendleton	DEERFIELD	dom	2	61,60	1953	dug		8/28/59	11,700	58,800	13
$72\text{-}A_2$		P.E. Pendleton	DEERFIELD	dom	2	61,60	1953	dug		8/28/59	15,700	78,900	11
86		Nellie O'Neal	DEERFIELD CENTER	dom	2	65,31	1949	drl	109	8/28/59	59,000	296,000	
129	*	Francis Harvey	W. NOTTINGHAM	dom	1	53	1957	drl	263	8/26/59	4,490	22,500	0
158	*	Harvey Lake Motel	NORTHWOOD	dom com	2	50,50	1954	dug	15	8/26/59	3,050	15,300	0.3
159	*	R.J. McDonald	NOTTINGHAM	dom	3	75,68 65	1954	drl	70	8/28/59	3,850	19,300	15
160	*	Bryon Littlefield	RAYMOND	dom	3	64,50 22	1945	drl	70	8/28/59	2,270	11,400	
161	*	H.L. Hutchinson	W. EPPING	dom	6	45,40 19,18 16,6	1959	drl	100	8/28/59	4,240	21,300	0

CONCENTRATION OF NATURAL RADIOACTIVITY IN WATER - (NEW HAMPSHIRE)

Sample Number	Name	Location	Use of Well	No. of Persons Using Well	Ages of Persons Using Water	Date Family Began to Use	Type of Well	Depth of Well (ft)	Date of Sample Collection	Activity of Rn-222 (μμc/l)	α+β Activity of Rn-222 + Dghtrs. thru Po-214 (μμc/l)	Activity of Ra-226 (μμc/l)
162A (#)	Thomas P. Sawyer	DEERFIELD CENTER	dom	3	63,62 34	1959	drl	145	8/28/59	486	2,440	
162B (")	Thomas P. Sawyer	DEERFIELD CENTER	dom	3	63,62 34	1959	drl	145	8/28/59	2,120	10,700	0
163 *	Roadside Spring	GRAFTON					sprg		8/31/59	1,220	6,130	5.7
164 *	J.F. Kuster	GRAFTON	dom	2	45,42	1956	driv	12	8/31/59	500	2,510	0
165 *	A.S. Gage	GRAFTON	dom	3	63,64 92		dug	9	8/31/59	1,230	6,180	0
166 *	Daniel W. Fell	WEBSTER GROVE	dom	2	77,43	1959	drl	101	8/31/59	509	2,560	8.1
167 *	P.J.DeFault	WEBSTER LAKE	dom	4	49,43 39,17	1953	drl	129	8/31/59	1,090	5,480	0
168 *	N.E. Howard	WEBSTER LAKE	dom	2	56,55	1959	drl	100	8/31/59	536	2,690	0
169 *	John Moyer	N. CHICHESTER	dom	6	39,31 12,11 7,6	1954	drl	212	8/31/59	27,100	136,000	
170 *	Clayton Weeks	PITTSFIELD	dom	5	37,35 11,10,8	1958	drl	144	8/31/59	5,000	25,100	
171 *	I. Gilbert	ALLENSTOWN	dom	5	51,47 27,25,15	1956	drl	130	8/31/59	725	3,640	

(#) Analysis of initial water from a new well (") Analysis of water after the first hour of pumping

APPENDIX C

APPROXIMATE LOCATION AND ACTIVITY OF SAMPLING POINTS IN MAINE AND NEW HAMPSHIRE (MAP)